Naval Research Laboratory
Washington, DC 20375-5320

NRL/MR/6180--97-7944

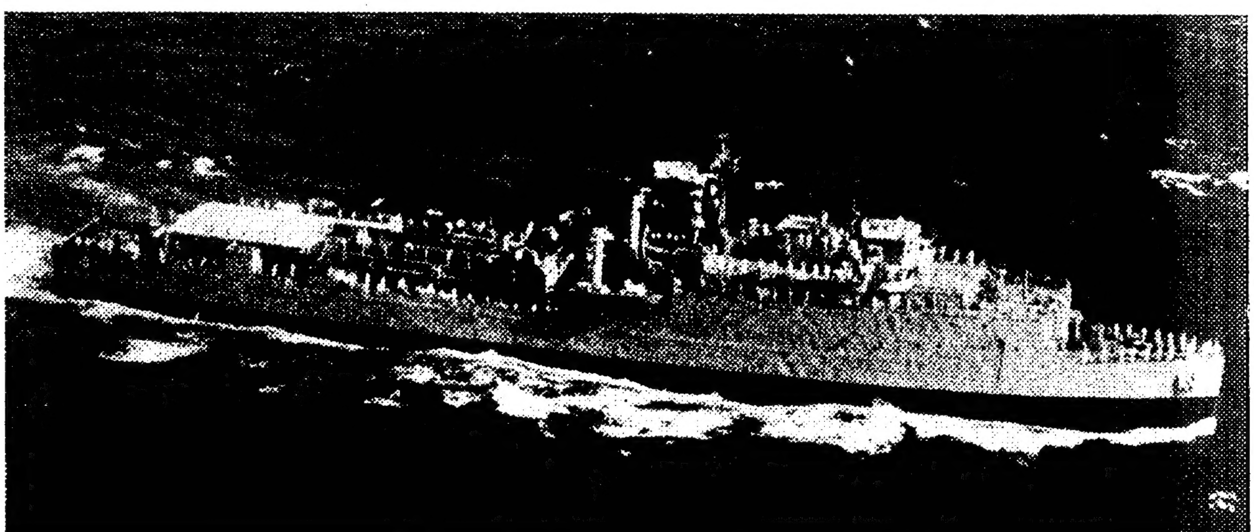
1994 Attack Team Workshop: Phase II - Full-Scale Offensive Fog Attack Tests

Joseph P. Scheffey
Charles W. Siegmann, III
Terrance A. Toomey

Hughes Associates, Inc., Baltimore, MD

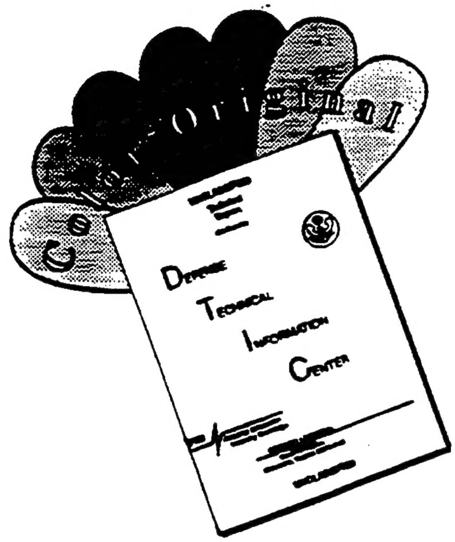
Frederick W. Williams
CDR John P. Farley

Navy Technology Center for Safety and Survivability
Chemistry Division



April 24, 1997

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 24, 1997	Workshop — FY 1994

4. TITLE AND SUBTITLE

1994 Attack Team Workshop: Phase II — Full-Scale Offensive Fog Attack Tests

5. FUNDING NUMBERS

PE - 64516N
PR - S2054

6. AUTHOR(S)

F.W. Williams, CDR J.P. Farley, C.W. Siegmann III,* J.P. Scheffey,* and T.A. Toomey†

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6180--97-7944

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Chief of Naval Operations (N86D)
Washington, DC 20350

Naval Sea Systems Command, Code 03R2
Washington, DC 22242

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Hughes Associated, Inc., Baltimore, MD
†Consultant

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (*Maximum 200 words*)

Shipboard firefighting is accomplished in one or a combination of three techniques: (a) for a incipient or growing fire, the preferred method is DIRECT ATTACK; (b) if the fire has grown beyond being handleable by the direct attack, the INDIRECT ATTACK is preferred followed by a direct attack; and (c) in large post-flashover fires, a CONTAINMENT strategy is first initiated following by indirect and then a direct attack.

This report demonstrates the benefits of using a medium angle fog stream to control the overhead fire threat when conducting a direct attack on a growing/steady state fire where the sea of the fire is obstructed. This greatly reduces the time required to control and extinguish a rapidly growing post flashover fire which previously could only be handled with the time-consuming techniques of indirect attack.

14. SUBJECT TERMS

ex-USS SHADWELL
Post-flashover
Containment
Offensive fog attack

15. NUMBER OF PAGES

306

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

CONTENTS

1994 ATTACK TEAM WORKSHOP: PHASE II - FULL-SCALE OFFENSIVE FOG ATTACK TESTS

INTRODUCTION

This report describes testing conducted on board the ex-USS SHADWELL, the Navy's full-scale damage control R&D platform [1]. The subject tests represent Phase II of the 1994 Attack Team Workshop (ATW) test series and are designed to provide the technical and scientific basis for changes and improvements to Naval Ships' Technical Manual (NSTM) 555 [2]. Similar testing has been conducted in previous years as part of the Fleet Doctrine Evaluation (FDE) test series with topics including indirect attack of mass conflagrations, active desmoking of below-deck fires, vertical fire attack, smoke and heat management, and boundary cooling/containment techniques [3-6].

At the 1993 Annual DC/FF Working Group meeting, the aggressive use of water fog for firefighting purposes was proposed. NSTM 555 currently recommends a narrow angle fog or straight stream for direct fire attack into the base of Class A fires. Where a compartment is heavily involved in fire, a side-to-side sweeping action, again using a narrow angle fog or straight stream, is recommended. Participants of the working group agreed that alternative techniques for application of water fog streams should be a topic of investigation. Accordingly, the 1994 Attack Team Workshop test series was developed to evaluate techniques for application of water fog streams to control a growing/fully developed fire threat. Specifically, the use of a medium (approximately 60°) angle fog directed at a 45° angle up into the overhead and discharged in short bursts was compared with the traditional straight stream attack.

As performed during previous FDE testing, ancillary tests were conducted concurrently with the attack team evolutions. Evaluations conducted by the Naval Health Research Center (NHRC) included continuation of the psychological studies initiated in the 1993 FDE test series as well as collection of physiological data and monitoring of specific garment characteristics. Evaluations conducted by the Naval Clothing and Textile Research

Manuscript approved March 11, 1997

Facility (NTRF/20) included modifications to the firefighters' boots and gloves. A nonfirefighting evaluation of a proposed Self-Contained Breathing Apparatus (SCBA) was performed by participants not directly involved in the attack team evolutions.

The objective of this report is to document the test setup for the attack team evolutions, describe the results of the firefighting tests, provide representative data of the fire threat, and analyze the results in the context of changes to NSTM 555. It is expected that principal investigators/project managers for the ancillary tests will prepare individual reports/videos/presentations.

BACKGROUND

Current Doctrine

Section 5.3 of NSTM 555 [2] outlines current U.S. Navy doctrine relative to shipboard interior firefighting tactics. Paragraph 555-5.3.2.7.1 describes the main objective of fire attack as being "... to gain immediate control and to prevent or minimize the spread of fire." The key phrase in this passage is "to gain control;" if the firefighter is able to gain immediate control of the fire, the task of preventing or minimizing fire spread will be greatly simplified. The question then is how best to gain immediate control of the fire.

Paragraph 555-5.3.2.7.1 goes on to describe two basic methods of attack that will allow the firefighters to control the fire and minimizing fire spread. These two methods are the direct attack and the indirect attack. A direct attack is used when the firefighters can "...advance into the immediate fire area and apply the extinguishing agent directly onto the seat of the fire." The indirect attack method is used when "...heat, gases, and smoke from an advanced fire make access increasingly difficult." In this respect, the current doctrine is limited. The direct attack method is acceptable for incipient or growing, unobstructed fires while the indirect attack method is applicable to the post flashover/fully developed fire

scenario[1]. The limitation is that there are a wide range of fires that could potentially fall in between these two extremes for which neither of the described attack methods would be the most advantageous.

Fire scenarios that would fall between the two extremes include the following:

- growing/steady state fires where the seat of the fire is shielded from direct agent application by an obstruction;

- growing/steady state fires where there are multiple fire sources scattered about the space; and

- low visibility fires where heat and heavy smoke conditions obscure the seat of the fire.

The conditions (heat, smoke, and fire gases) associated with these fire scenarios typically do not prevent initial entry into the fire compartment. However, the extra time that it takes to maneuver within a space to locate and directly attack the seat of the fire does present a significant threat, primarily due to the stage of the fire. Uncontrolled, these fires may continue to grow rapidly, potentially resulting in flashover conditions. This is particularly true where the fire is ventilation limited (due to "button-up" procedures by investigators) and entry by the attack team introduces additional air. These types of fires require a quick decision whether to continue with the direct attack or fall back for an indirect attack. This decision must be continually reevaluated as time passes and conditions change.

---

[1] The terms incipient, growing, fully developed, and flashover describe different states of fire involvement. These terms have been quantitatively described in previous Naval Research Laboratory (NRL) firefighting doctrine reports [6, 7]. They are also described in NSTM 555 [2].

This ongoing decision making process, which involves constant reevaluation of the conditions in a hostile environment, can be difficult even for an experienced firefighter who has been in the same situation many times previously. Paragraph 555-5.3.2.7.2 describes "...training, discipline, and courage..." as necessary characteristics for a nozzleman or attack team leader. Because fires of this magnitude aboard Navy ships are infrequent, the experience level of Damage Control Teams is correspondingly low. Also, current training focuses primarily on the physical tactics associated with the two attack methods without emphasizing the decision making process. As a result, the development of a simple firefighting tactic that does not involve complicated decision making is appropriate. This tactic should allow the firefighter to quickly gain and maintain control of the fire environment to meet the challenges of growing/steady state obstructed or low visibility fire threats. One such tactic is the use of medium angle fog in short bursts directed up in the hot layer. This type of tactic has been described in several civilian firefighting manuals and articles [8, 9, 10, 11]. When properly executed, this tactic has the advantage of efficiently cooling the hot gas layer without generating excessive amounts of steam. It can also reduce disruption of the thermal balance within the fire space[2]. The net effect is to maintain tenable conditions within the fire space, thereby allowing the firefighters to continue with their efforts to locate and extinguish the seat of the fire.

Current doctrine refers only to the straight stream and narrow angle (30°) fog settings of the vari-nozzle when addressing direct fire attack (paragraphs 555-5.3.2.7.3, 555-5.3.3.3.2, 555-5.3.3.3.6, and 555-5.3.4.2, Item 11). References to the use of medium or wide angle fog are limited to defensive situations or general cooling of the hot gas layer (paragraph 555-5.3.2.7.3, 555-5.3.3.3.6, 555-5.3.4.2, Item 11, and 555-5.3.10.4). The rationale for this philosophy is found in paragraph 555-5.3.3.3.2, "... visibility and comfort are paramount for an effective attack. Fog streams greater than 30 degrees, discharged onto a heated overhead...will create steam...[which] will surround the firefighters, causing burns

[2] The term "thermal balance" as used in NSTM 555 refers to the condition where the atmosphere in the fire compartment has settled into two distinct layers with the smoke and hot gases in the upper layer and cooler fresh air in the lower layer.

and discomfort and will disrupt the thermal column and heat in the overhead, causing a thick smoke layer to descend and reduce visibility." This rationale was developed from previous NRL firefighting doctrine tests [7, 12].

Visibility and comfort are important factors, particularly from the standpoint that if you get forced out of the space by steam, you have lost territory which could be hard to take back. However, the threat posed by the build-up of hot gases in the overhead while attempting to locate and attack the seat of the fire is of equal importance. A tactic that will allow the firefighter to control the overhead threat without adversely affecting visibility and comfort would allow a more aggressive attack. The ability of medium angle fog to cool the hot gas layer has already been acknowledged. If an offensive tactic using a medium angle fog stream can be developed that would not produce the adverse affects on visibility and comfort, the firefighter would have the tool he needed.

In summary, the success of a direct fire attack performed in accordance with current Fleet Doctrine is dependent on the seat of the fire being readily accessible to the attack team and limiting the steam insult to the firefighters. If this is not the case and the attack team is unable to gain quick control of the fire, the only option currently described is to fall back and perform an indirect attack. There is minimum guidance either from the doctrine or from the training community to help the firefighters with the decision making process that is required for changing conditions. The use of a medium angle (60°) fog stream directed upward at a 45°angle at the burning gases in the overhead has been identified as a tactic that could be used in such situations. By controlling the overhead fire threat first, the attack team may have more time to locate the seat of an obstructed or low visibility fire. They might also have sufficient time to evaluate conditions and make the necessary decision for continuing a successful direct attack.

Phase I Scoping Test

Unlike previous FDE test series, the initial scoping tests for the 1994 ATW were performed in the USS STARK mockup located at the Chesapeake Beach Detachment (CBD) of the Naval Research Laboratory, rather than onboard the ex-USS SHADWELL.

These scoping tests established two different repeatable and challenging fire threats and evaluated the effects of variables such as flow rate and tactics on the ability to control and knockdown the fire.

Reference [13] describes the results of these tests. At the 76 Lpm (20 gpm) flow rate, the offensive fog technique appeared to be a better tactic than the traditional straight stream approach. At the 360 Lpm (95 gpm) flow rate, the differences between the two techniques were not significant. This was attributed to the size and volume limitations of the CBD test space. Most importantly, these tests demonstrated that under certain conditions, a medium angle (60°) fog stream could be used as an offensive tactic to control and knockdown the fire in the overhead without adversely affecting the thermal balance and tenability within the fire space. The primary limitation of these tests was the relatively small size of the fire space. This is one reason why differences between tactics were not observed at the high (360 Lpm (95 gpm)) flow rates.

OBJECTIVES

The objective of the Phase II Attack Team Workshop test series was to define scenarios where an offensive fog attack might be used to control the fire threat. More specifically, these tests were intended to determine the benefits and drawbacks of using an offensive fog attack versus a traditional straight stream attack to control a growing/steady state fire threat. They also provided an opportunity to identify specific techniques for optimizing the use of an offensive fog attack.

APPROACH

The Phase II Attack Team Workshop tests were conducted in the forward area of the ex-USS SHADWELL, on the first (main) and second decks between FR 9 and 22 (Figs. 1 and 2). The actual test area was the second deck, between FR 15 and 22, in the space formerly designated as Berthing 1 (2-15-2). This space was modified for the Attack Team Workshop test series by adding a fore-to-aft bulkhead down the centerline of the

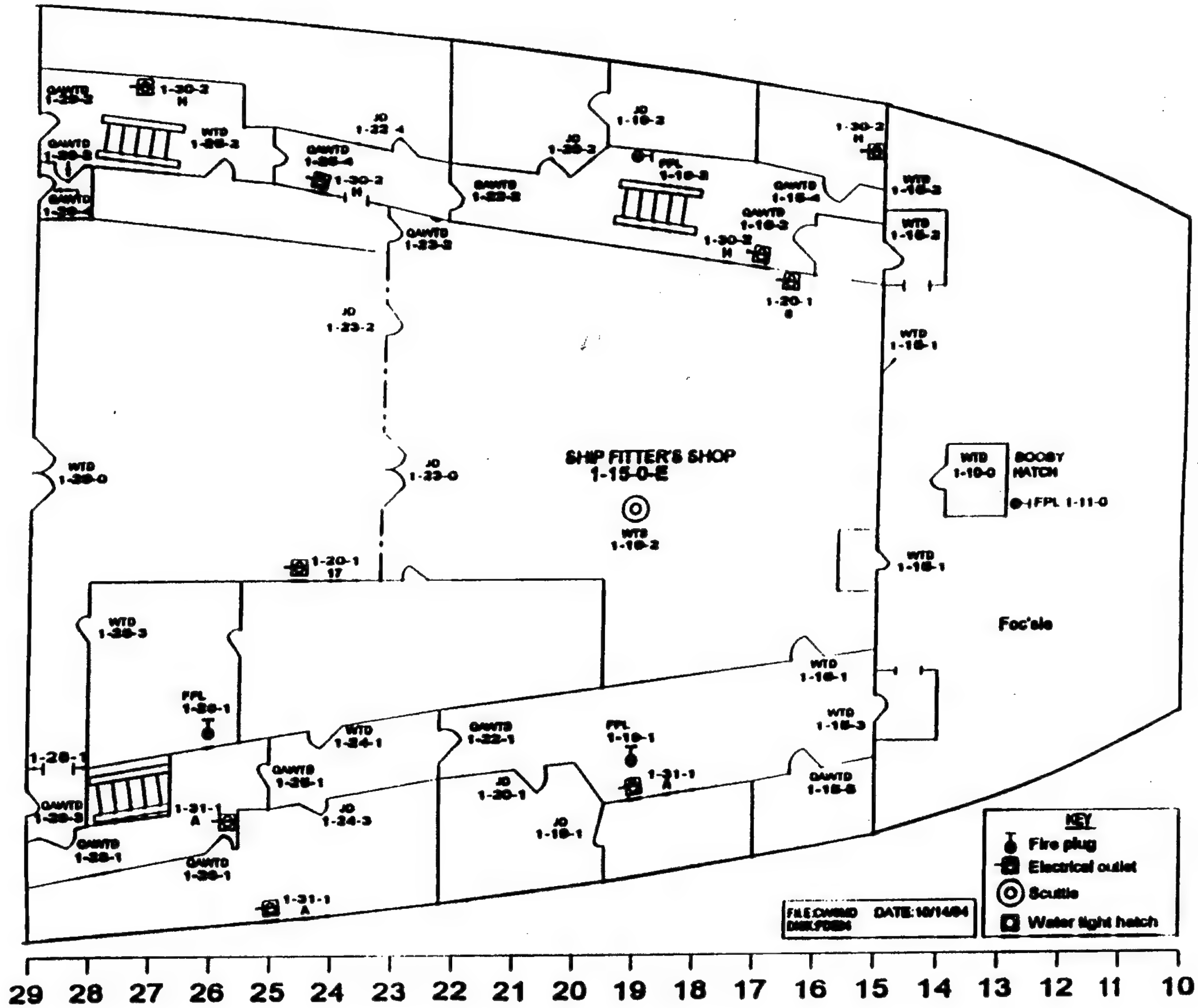


Fig. 1 - First (Main) deck plan view, FR 10-29

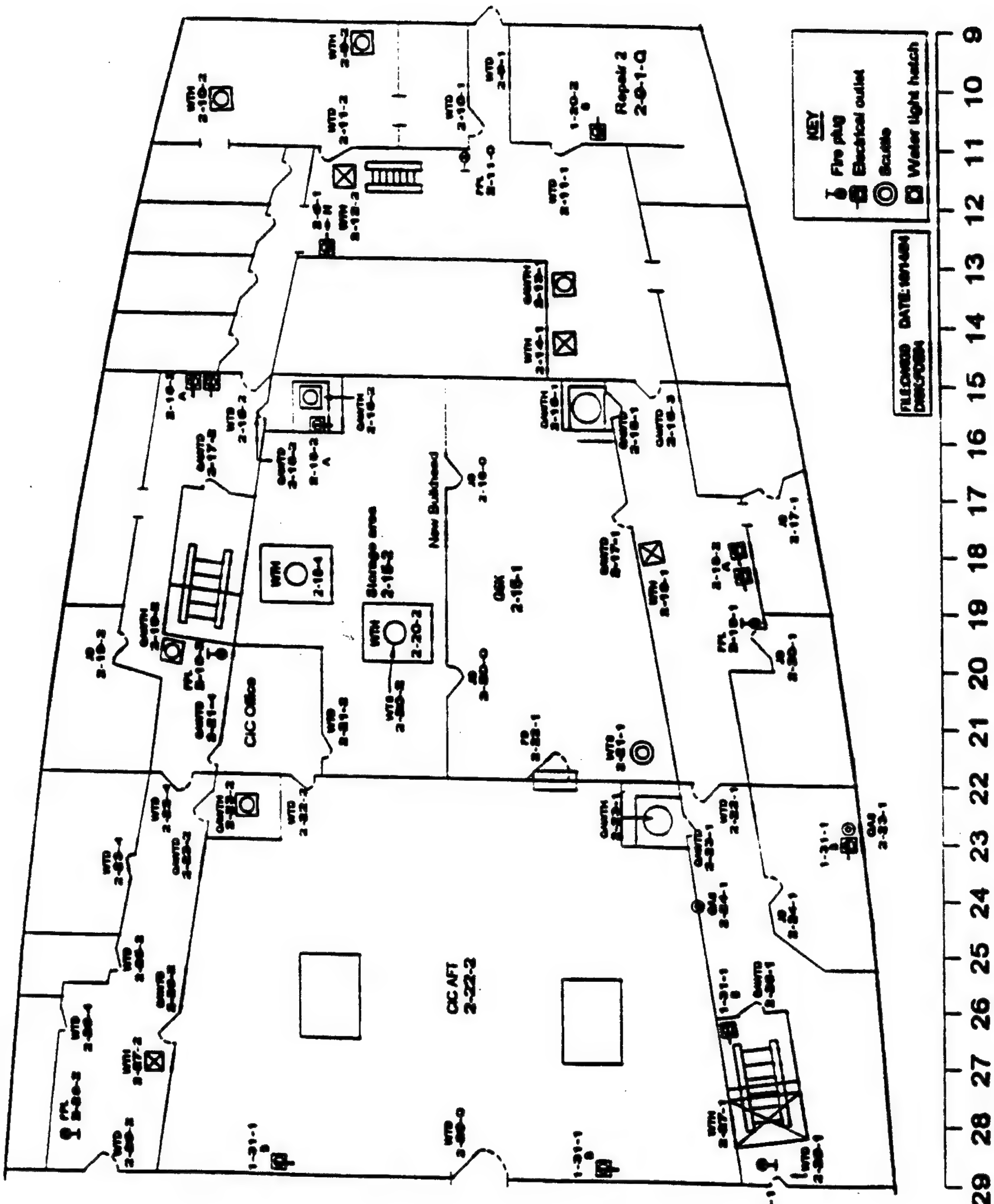


Fig. 2 - Second deck plan view, FR 9-29

compartment. The new space to port of the centerline bulkhead was designated as Storage Area (2-15-2) while the space to starboard was designated as General Store Keeping Office, (GSK 2-15-1) (Fig. 3).

The fire area was in the aft portion of the Storage Area. Access to the fire area was via the starboard passageway through watertight door QAWTD 2-17-1 into GSK, and then though the forward joiner door JD2-16-0 into the fire space. Repair 2 (2-9-1-Q) was used as the staging area for the attack team. The fo'c'sle area forward of the ship fitters shop (1-15-0-E) on the main deck and CIC Aft (2-22-2) on the second deck served as emergency escape and muster areas.

The Phase II test series involved combating a Class A growing/steady state fire using a horizontal attack through an uninvolved adjacent compartment. Test variables included firefighting tactics for controlling/extinguishing the fire, effects of obstructions, and effects of visibility. Safety warm-up tests were conducted 15-19 August 1994.

Fire Threat No. 1, used for the initial six tests of the September series was a growing/steady state Class A fire involving wood cribs, particle board panels, and newspaper filled cardboard boxes. For this scenario, the fire sources were obstructed by metal partitions and lockers. This forced the attacked teams to advance well into the compartment before being able to apply water directly to the seat of the fire. Also, to add to the difficulty of the evolution, none of the participants were allowed to observe the layout of the compartment prior to entering it for their first firefighting attempt.

Fire Threat No. 2, referred to as the "low visibility" scenario, was similar in lay out to threat No. 1 except that oil-soaked rags were substituted for one of the wood cribs and the particle bound sheets were not included. The fire space was increased to include GSK by leaving the forward joiner door (JD-2-16-0) open, and the obstructions present for threat

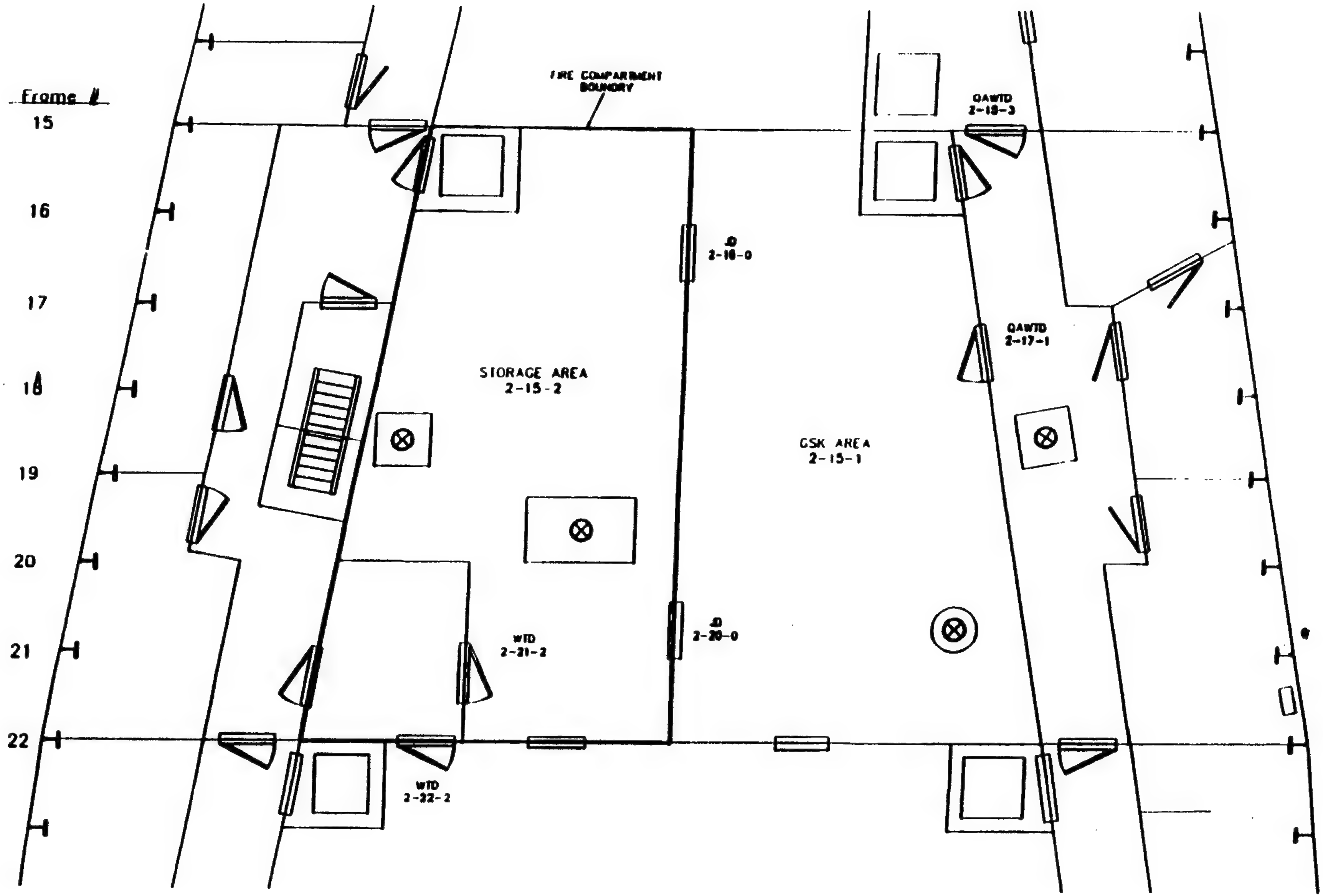


Fig. 3 – Second deck test area plan view (FR 15–23)

No. 1 were not present, having been removed for a previous test. As with the initial tests for threat No. 1, the attack team was unaware of the new layout of the fire space.

After the initial set of tests were conducted with fire threat No. 1, it was decided that a set of two tests should be conducted without the obstructions in place. This revised threat was designated as Fire Threat No. 1A. In all aspects other than removal of the obstructions, it was identical to Threat No. 1. Attack team members fighting this fire were not advised as to the changes in the compartment layout.

Three groups of participants were used to form three attack teams. All participants were fleet personnel and included a damage control team from the Precommissioning Unit of the RUSSEL (DDG 59), a team of Propulsion Examination Board (PEB) personnel from both the Atlantic and Pacific Fleets, and an all-female team formed from firefighting instructors from FTC Treasure Island and Repair Party members from the USS EMORY S. LAND. Each team consisted of an Attack Team Leader, a nozzle man, a hose man, and a plugman/back-up.

The scope of these tests was limited to the control and extinguishment of a growing/steady state Class A fire confined to a single compartment. Fire spread was not considered; e.g., boundaries were not set and there was no active desmoking/ventilation. Prior to the initial tests, all teams conducted hoseline drills so that both tactics (traditional straight stream and aggressive fog) were well understood. Additionally, the test matrix was arranged so that proficiency and knowledge of the fire space layout gained from the first three tests did not bias either tactic.

The proposed test plan for the Phase II September test series is described in Reference [14].

FIRE THREAT

One of the principle objectives for these tests was to provide realistic fire threats that would result in a severe challenge to attack teams attempting a traditional direct attack using a straight or narrow angle fog stream as described in NSTM 555. The fire threats also had to be repeatable to allow for evaluation and comparison of the test results independent of fire related variables. As a result of the Phase I Scoping Tests and the Phase II Safety Warm-Up tests, the two fire threats described previously were developed. It was determined that these two threats would provide the challenge and repeatability needed.

The first fire threat (Fire Threat No. 1) was intended to represent a growing/steady state fire that had multiple fire source locations dispersed about the fire compartment which created flashover or near flashover conditions in the space. Flames rolling across the overhead and upper layer temperatures in the range 400-600°C (752-1112°F) typified this type of fire. To provide further challenges and realism to the attack teams, obstructions were placed between the fire sources and the entry point to the fire compartment. This forced the attack team to advance well into the space, under severe conditions, to directly attack and extinguish the sources of the fires. In order to successfully approach the fire sources, the attack had to first control the fire in the overhead.

The second fire threat was intended to represent a low visibility fire. While typically not as hot, this type of fire does pose a significant challenge in locating the seat of the fire. Also, as more time is spent locating the seat of the fire, conditions can continue to deteriorate, and eventually the hot gases collecting in the overhead may become a very real threat. Therefore, controlling action is again needed to maintain tenability and safety within the space. Oil-soaked rags in place of one of the cribs, and n-Heptane mixed with diesel fuel as the initiating fuel were used to provide this type of scenario.

EXPERIMENTAL SET-UP AND PROCEDURE

General Set-Up

Figures A1 and A2 in Appendix A provide dimensional details of the main and second deck forward areas. The second deck is shown as modified with the new centerline bulkhead and joiner doors. The staging area for the attack team was Repair 2 (2-9-1-Q). Accesses used by the attack team to reach the fire space included QAWTD 2-15-3, QAWTD 2-17-4, and JD 2-16-0. The dimensions of the quick acting watertight doors were 168 x 66 cm (66 x 26-in.) and the joiner doors in the new centerline bulkhead were 213 x 61 cm (84 x 24-in). Emergency exit routes available to the attack team were FD 2-22-1 to the CIC Aft safety area, or QAWTD 2-17-1 and QAWTD 2-15-3 back to Repair 2 and then up to the fo'c'sle via the booby hatch at FR11.

Simulation of a typical storage area was accomplished by having three separate fire sources within the fire area. The exact locations of the fire sources are shown in Fig. 4. Each fire source consisted of a wood crib in combination with particle board panels and newspaper filled boxes (Figs. 5, 6). Each fire source location had a metal pan located below the wood crib for initiating fuel. Additional details pertaining to the fire sources are presented in Section 5.3. To further simulate a storage area, and the make the attack more challenging, metal panels, lockers, and cabinets (Fig. 7) were placed around the compartment so that they obstructed the fire sources. The metal panels were all 1.2 m (4 ft) high. The dimensions of the lockers are provided in Fig. 4. The exact locations of the obstructions are also shown on Fig. 4.

Ventilation

The ventilation used for these tests was supplied from the ships ventilation system, TPSS (Total Protection Supply System), and TPES (Total Protection Exhaust System). The supply system outlet for the test area was located near the aft bulkhead of the

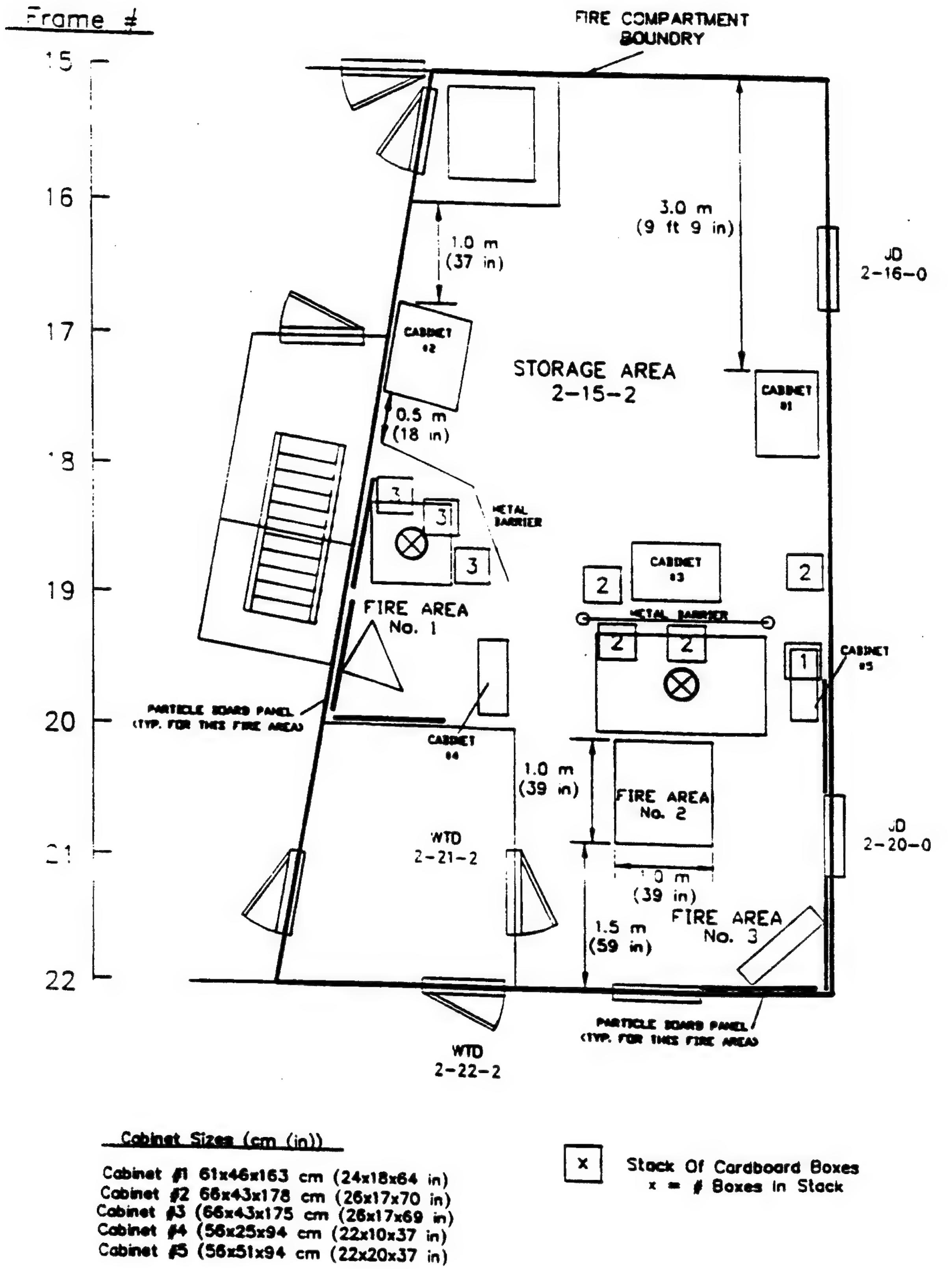


Fig. 4 – Second deck fire source and obstruction layout plan view (FR 15–22)

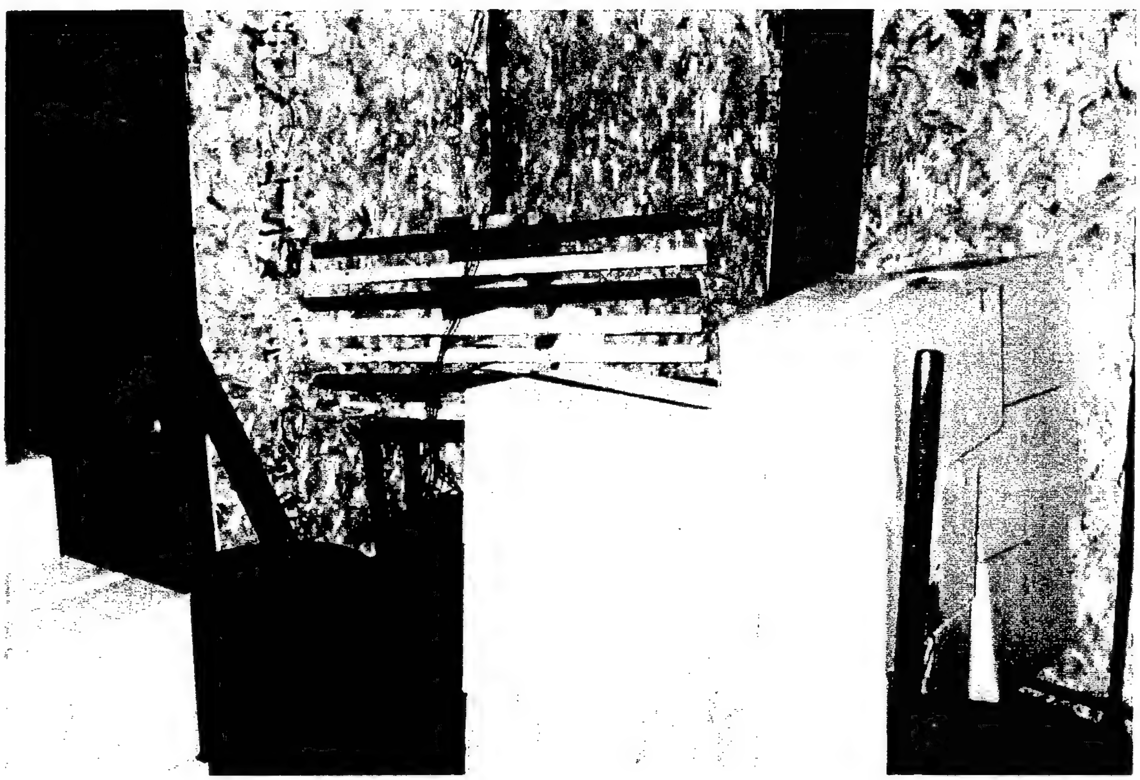


Fig. 5 - Wood crib, particle board panels, and newspaper filled boxes at Fire Source No. 1 (shown without obstructions)

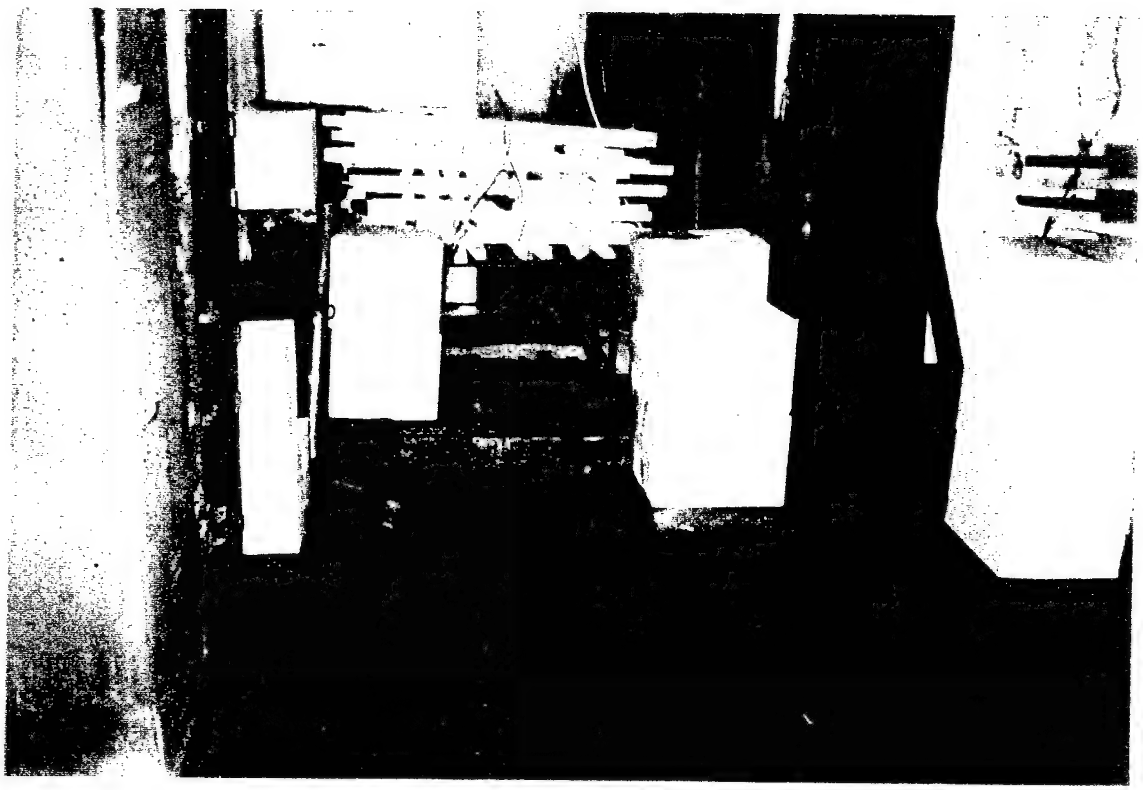


Fig. 6 - Wood crib and newspaper filled boxes at Fire Source No. 2
(shown without obstructions)

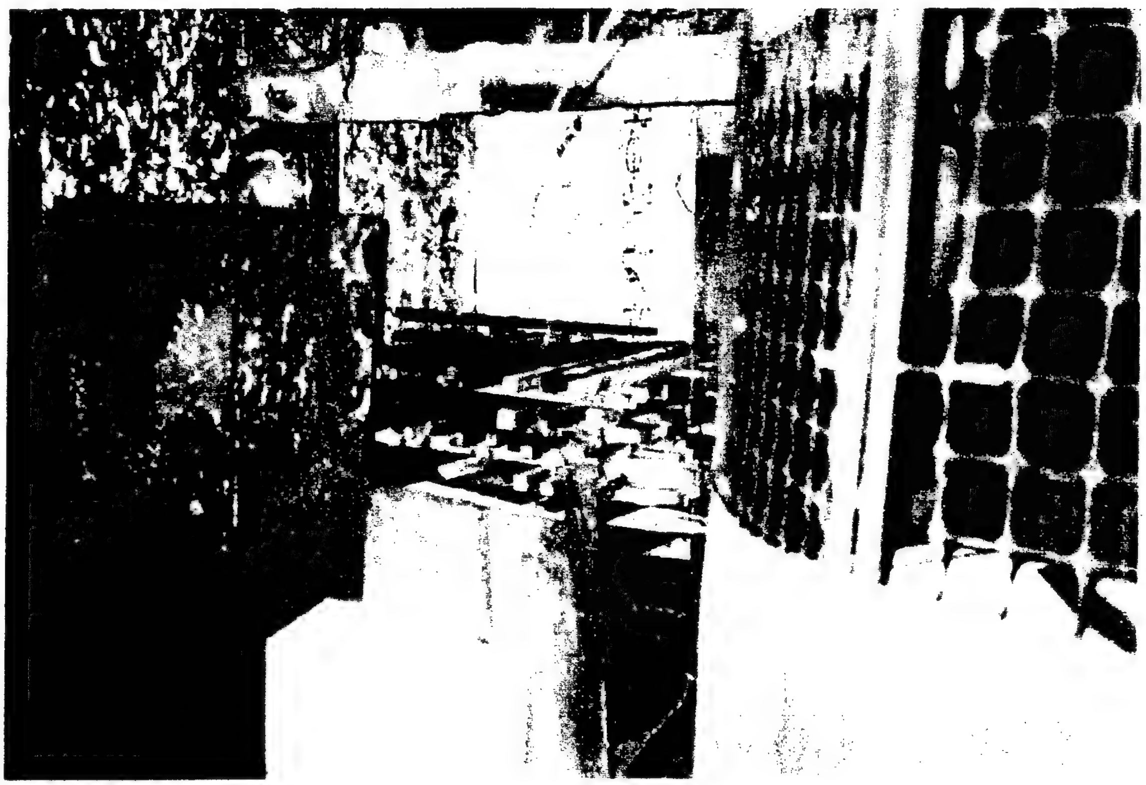


Fig. 7 - Obstructions located in front of Fire Source Nos. 1 and 2

Storage Area in the overhead and had a measured flow of 3822 Lpm (135 cfm). The exhaust inlet was located at approximately the center of the Storage Area in the overhead and had a measured flow of 44369 Lpm (1567 cfm).

Additional fresh air was supplied to the fire space during the fire build-up phase from CIC Aft (2-22-2) via the CIC Office. This was accomplished by leaving WTD 2-22-2 fully open and throttling the air flow with WTD 2-21-2. Just prior to the attack team entering the fire space, WTD 2-21-2 was closed. The f-stops on the exhaust system shafts located at FR15 were left open to provide a natural ventilation path for the fire space. For Fire Threats No. 1 and No. 1A, F-stop 2-15-2 was left open. For Fire Threat No. 2, F-stop 2-15-1 was left open. Both of these exhaust paths discharged to weather at the O2 Level. The fans on these systems were not activated during the firefighting evolution, however, after the fire was declared out, they were turned on to expedite desmoking of the test area.

The LPSS (Limited Protection Supply System) and LPES (Limited Protection Exhaust System) located in the DDG 51 machinery space was not used during the test. This system was activated only for post-exercise desmoking.

Fuel Packages

There were two basic fuel loads used for these tests. For Fire Threats No. 1 and No. 1A, the fuel load consisted of three wood cribs, six particle board panels, and 18 newspaper filled cardboard boxes. The wood crib fires were initiated by n-heptane pool fires. For Fire Threat No. 2, the fuel load consisted of two wood cribs, 18 newspaper filled cardboard boxes, and a bundle of oil-soaked rags. For this fire threat, the wood cribs fires were initiated by a diesel/n-heptane mixture, while the rags were ignited directly by the torch. For all three fire threats, the fuel loads were located as shown in Fig. 4. Table 1 summarizes wood crib construction details and fuel load arrangement for Fire Threats No. 1 and No. 1A. Table 2 summarizes the fuel load arrangement for Fire Threat No. 2.

Table 1. Fuel Load for Fire Threats No. 1 and No. 1A

Fire Source Location	Wood Crib Plan View Shape	Wood Crib Construction	Initiating Fuel	Particle Board Panels	Cardboard Boxes
1	Triangular	14 Rows of 2 sticks each, alternating pattern; - Bottom row had 1-122 cm (48-in.) and 1-45.7 (18-in.) spaced 30.5 cm (12-in.) apart; - Next row had 2-45.7 cm (18-in.) at 90° angle to each other; - Top row had 3-45.7 cm (18-in.) space 15.2 cm (6-in.) apart.	11.6 L (3 gal) n-Heptane in 61 cm (24-in.) diameter pan Note: reduced to 2.8 L (3/4 gal) for Test FOG_15 Note: reduced to 1.9 L (1/2 gal) for Tests FOG_16 through FOG_19	3 Total: - 2 on Port Bulkhead - 1 on Forward CIC Office Bulkhead	9 Total: - 3 stacks of 3 between crib and obstruction
2	Square	10 Rows of 10 sticks each, all 122 cm (48-in.) long spaced 2.5-5.1 cm (1-2-in.) apart.	18.9 L (5 gal) n-Heptane in 91.4 cm (36-in.) square pan	None	9 Total: - 1 stack of 2 in front of obstruction; - 3 stacks of 2 between crib and obstruction; - 1 on cabinet next to centerline bulkhead
3	Rectangular	14 Rows of 2 sticks each, alternating pattern: - Bottom row had 2-122 cm (48-in.) spaced 30.5 cm (12-in.) apart; - Next roe had 2-45.7 cm (18-in.) spaced 6 cm (24-in.) apart	11.6 L (3 gal) n-Heptane in 61 cm (24-in.) diameter pan	3 Total: - 2 on centerline bulkhead - 1 on aft bulkhead	None

Table 2. Fuel Load for Fire Threat No. 2

Fire Source Location	Wood Crib Plan View Shape	Wood Crib Construction	Initiating Fuel	Particle Board Panels	Cardboard Boxes
1	Triangular	22 Rows of 2 sticks each, alternating pattern: - Bottom row had 1-122 cm (48-in.) and 1-45.7 cm (18-in.) spaced 305. cm (12-in.) apart; - Next row had 2-45.7 cm (18-in.) at 90° angle; - Top row had 3-45.7 cm (18-in.) space 15.2 cm (6-in.) apart	7.6 L 92 gal) diesel, 3.3 L (1 gal) n-Heptane in 61 cm (24-in.) diameter pan	None	9 Total: - 3 stacks of 3 forward of crib
2	N/A	Pile of oil-soaked rags placed in initiating fuel pan	3.8 L (1 gal) n-Heptane dumped on rags	None	9 Total: - 4 stacks of 2 in front of crib - 1 on cabinet near centerline bulkhead
3	Rectangular	25 Rows of 2 sticks each, alternating pattern: - Bottom row had 2-122 cm (48-in.) spaced 30.5 cm (12-in.) apart; - Next row had 2-45.7 (18-in.) spaced 61 cm (24-in.) apart	7.6 L (2 gal) diesel, 3.8 L (1 gal) n-Heptane in 61 cm (24-in.) diameter pan	None	None

The wood cribs (Figs. 8-10) were made from red oak sticks cut to a nominal size of either 5.1 x 5.1 x 122 cm (2 x 2 x 78-in.) or 5.1 x 5.1 x 45.7 cm (2 x 2 x 18-in.). The cribs were assembled in place on metal grate support stands that were 58.4 cm (23-in.) high. Each crib had a different plan view shape, as described in Tables 1 and 2. Under each stand was a metal pan to hold the initiating fuel. The amount of fuel used varied by location and is also detailed in Tables 1 and 2.

The particle board panels were made by nailing together two 6.4 mm (0.25-in.) thick 1.2 x 2.4 m (4 x 8 ft) sheets of particle board. This gave an overall panel thickness of 1.3 mm (0.5-in.). The panels were placed vertically against the walls of the compartment at the locations shown in Fig. 4 and the crib support stands or cardboard boxes were pushed against them to support them in place as shown in Fig. 5.

The boxes were made of corrugated cardboard and measured 45.7 x 38.1 x 30.5 cm (18 x 15 x 12 in.). They were filled with loosely crumpled newspaper and then taped shut. Their locations within the fire space are shown in Figs. 4, 5 and 6.

Instrumentation

The locations of all instrumentation used in the forward test area are shown in Appendix A, Figs. A3 and A4. The Appendix also provides details on instrumentation that was out of service for specific tests. Key instruments located in the second deck test area are shown on Fig. 11 and described below. The symbol legend for the instruments shown in Fig. 11 is provided in Appendix A.

Thermocouples

Type K, inconel-sheathed thermocouples, 3.2 mm (0.13-in.) outside diameter and 1.6 mm (0.06-in.) outside diameter, were used to measure air, overhead, crib flame, and

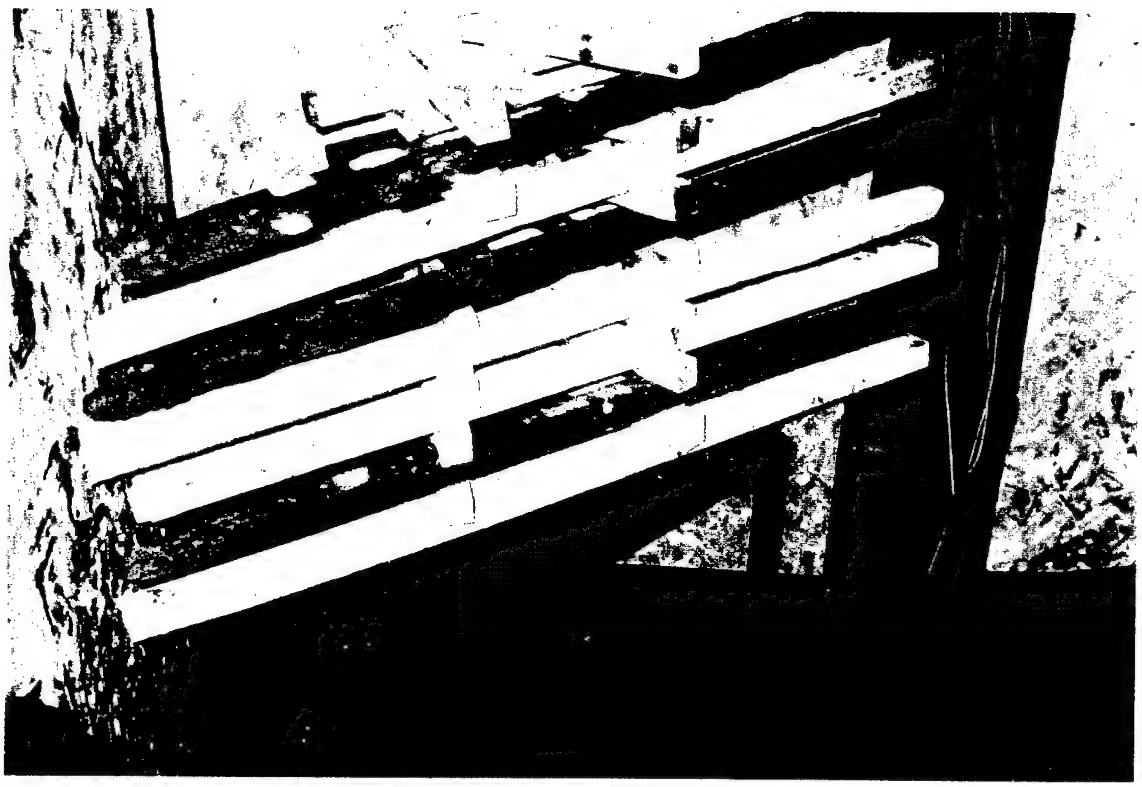


Fig. 8 - Triangular shaped wood crib located at Fire Source No. 1

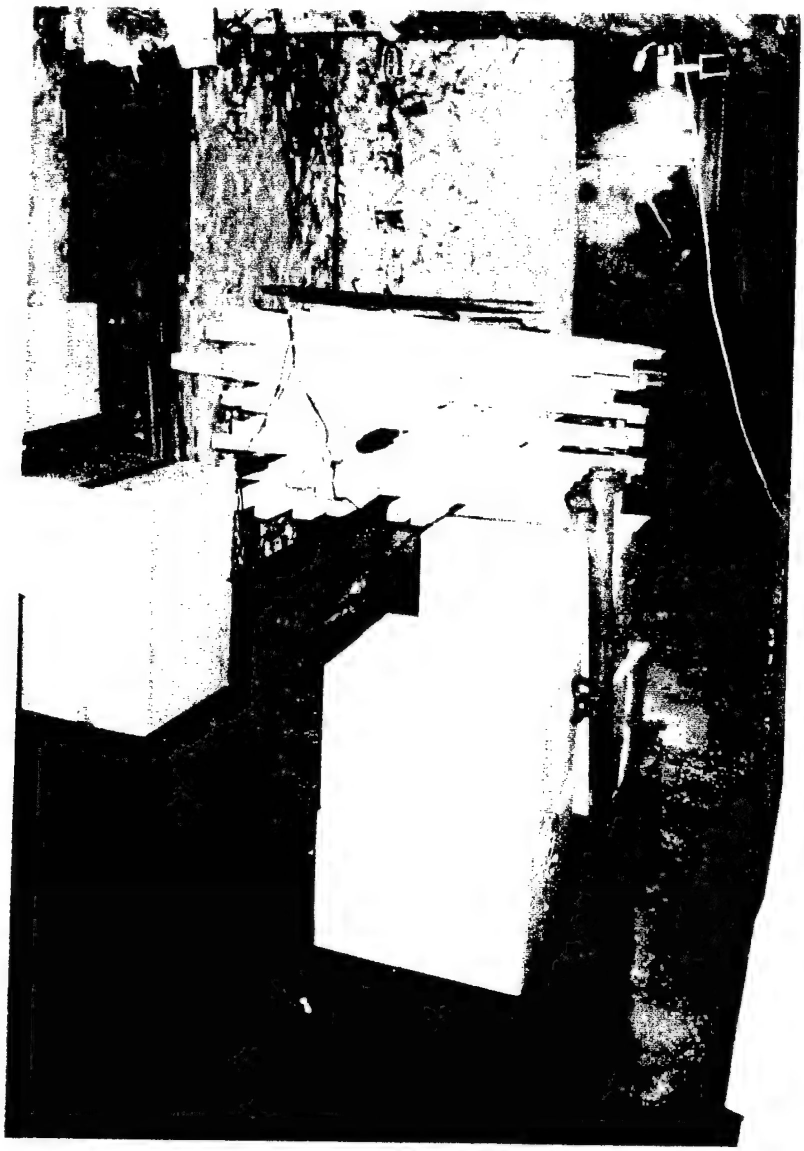
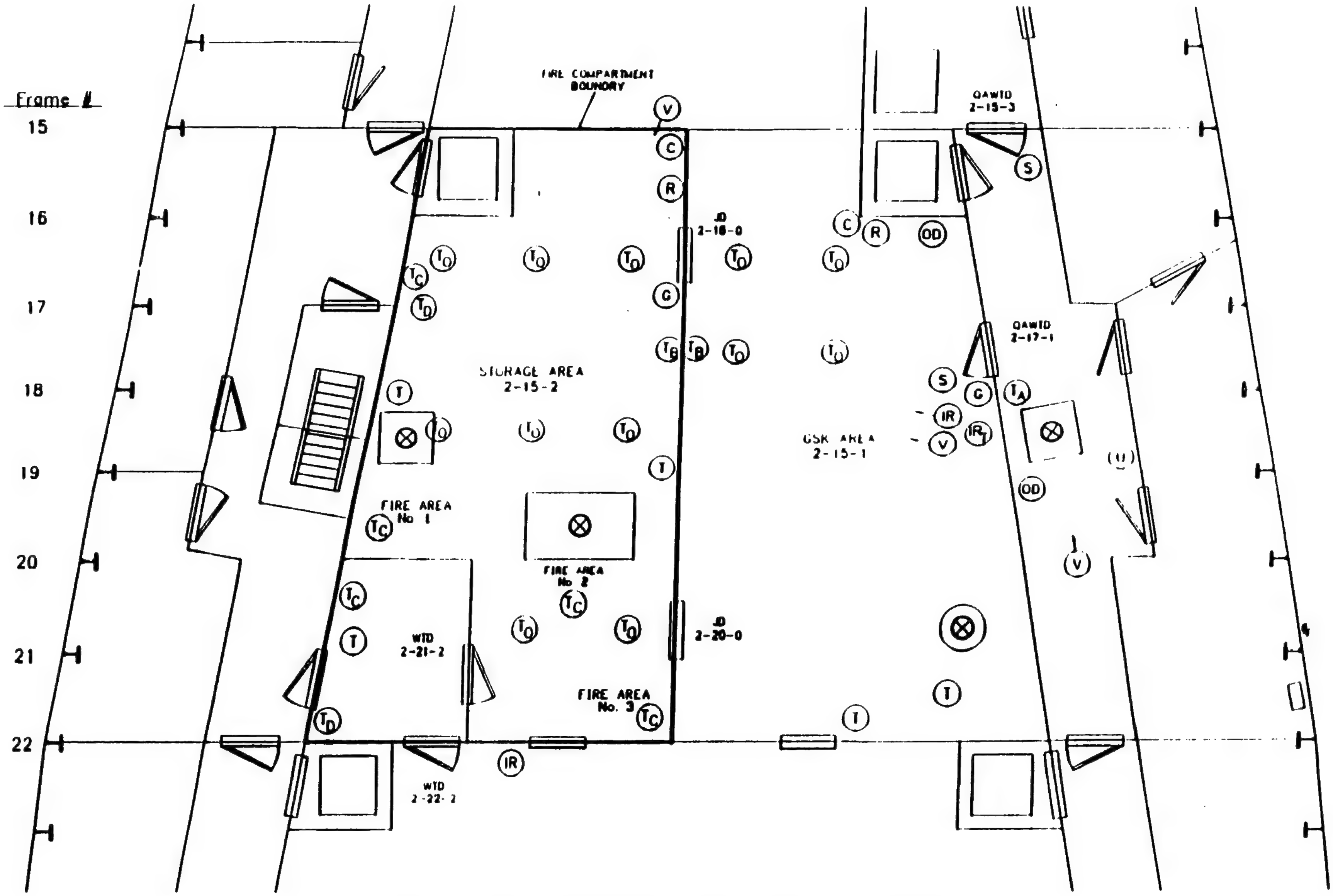


Fig. 9 - Square shaped wood crib located at Fire Source No. 2

Fig. 10 - Rectangular shaped wood crib located at Fire Source No. 3



Note: See Appendix A for Symbol Legend

Fig. 11 – Second deck test area instrumentation layout plan view (FR 15–23)

structural element temperatures. Key thermocouples located in the fire space (Storage Area) included the following:

1. Two vertical strings mounted on stands located at FR 18 on the port side of the compartment (2-18-2) and at FR 19 on the starboard side of the compartment (2-19-0). The thermocouples were mounted on the stands at 45.7 cm, 91.4 cm, 137.2 cm, 228.6 cm, and 274.3 cm (18 in., 36 in., 54 in., 72 in., 90 in., and 108 in.) above the deck.

2. Overhead thermocouples mounted 15.2 cm (6 in.) below the overhead were located in the bays between FRs 16 and 17, FRs 18 and 19, and FRs 20 and 21. The forward two bays had three thermocouples, positioned 71.1 cm, 215.9 cm, and 360.7 cm (28 in., 85 in., and 172 in.) out from the center-line bulkhead. The aftmost bay had only two thermocouples positioned 71.1 cm and 215.9 cm (28 in. and 85 in.) out from the center-line bulkhead.

3. Thermocouples were extended down from the overhead at each of the fire source locations. Fire Sources No. 1 and No. 2 each had three thermocouples, which were positioned in the center of the crib at the bottom, middle, and 30.5 cm (12 in.) above the top of the cribs. Fire Source No. 3 had only two thermocouples, which were positioned into the center of the crib at the bottom and 30.5 cm (12 in.) above the top of the crib.

Key thermocouples located in GSK included:

1. Two vertical strings located in the aft section of the space at FR 21, one mounted on a stand located just to the starboard of FD 2-22-1, the other mounted on a permanently affixed string located to starboard of WTS 2-21-1. Thermocouples on these strings were again mounted 45.7 cm, 91.4 cm, 137.2 cm, 182.8 cm, 228.6 cm, and 274.3 cm (18 in., 36 in., 54 in., 72 in., 90 in., 108 in.) above the deck.

2. Overhead thermocouples mounted 15.2 cm (6 in.) below the overhead were located in the bays between FRs 16 and 17, and FRs 17 and 18. Both bays had two thermocouples each, positioned 71.1 cm and 215.9 cm (28 in. and 85 in.) out from the center-line bulkhead.

An additional pair of thermocouples positioned at 45.7 cm and 152.4 cm (18-in. and 60-in.) above the deck were located in the starboard passageway just aft of QAWTD 2-17-1 to monitor the air temperature in the passageway.

Heat Flux Meters

Total heat flux was measured in the fire space (Storage Area) by calorimeters mounted on the center-line bulkhead just aft of FR 15 at 0.9 m and 2.4 m (3 ft and 8 ft) above the deck. The calorimeters (Medtherm Corp. serial numbers 85029 and 75131 respectively) both had a range of 0-56.8 kW/m^2 (0-5 Btu/ft^{2}s) and were oriented so that they viewed all three of the fire source locations.

Radiant heat flux was measured in the fire space by radiometers, also mounted on the center-line bulkhead immediately aft of FR 15 at 0.9 m and 2.4 m (3 ft and 8 ft) above the deck. The radiometer mounted at the 0.9 m (3 ft) level (Medtherm Corp. serial number 56935) had a range of 0-227.2 kW/m^2 (0-20 Btu/ft^{2}s) while the unit mounted at the 2.4 m (8 ft) level (Medtherm Corp serial number 50901) had a range of 0-56.8 kw/m^2 (0-5 Btu/ft^{2}s). Again both instruments were positioned so that they were able to view all three of the fire source locations.

Total and radiant heat flux was measured in the GSK area by a calorimeter and radiometer pair mounted 1.5 m (5 ft) above the deck on the port wall of the exhaust shaft supplying exhaust fan E1-15-1. The calorimeter (Medtherm Corp. serial number 71882) had a range of 0-227.2 kw/m^2 (0-20 Btu/ft^{2}s), while the radiometer (Medtherm Corp. serial number 50904) had a range of 0-56.8 kw/m^2 (0-5 Btu/ft^{2}s). Both units were oriented so that they viewed JD 2-16-0.

Optical Density Meters

Smoke obscuration was measured using optical density meters positioned 1.5 m (5 ft) above the deck at two locations. The first was mounted in GSK on the aft wall of the exhaust shaft supplying exhaust fan E1-15-1. The second was located in the starboard passageway between FRs 19 and 20. These units measured percent light transmitted and had a range of 0-100%.

Gas Analyzers

Gas analyzers were used to continuously monitor the oxygen (Beckman Model 755), carbon monoxide (Beckman Model 865) and carbon dioxide (Beckman Model 865) gas concentrations. The gas sampling lines were located in the fire space (Storage Area) at JD 2-16-0 and in GSK at QAWTD 2-17-1. There were two sampling lines at each location, one mounted 61.0 cm (24 in.) above the deck and one mounted 30.5 cm (12 in.) below the overhead. Because of problems with the analyzer, carbon dioxide measurements at 61.0 cm (24 in.) above the deck in the fire space could not be made.

Ultrasonic Flowmeters

Ultrasonic flowmeters (Controltron 9000 series) were used to monitor the water flow rates from fire plug FPL 2-19-1. Measurements were obtained from the starboard side fire main, via a mounting location at FR 23 on the main deck.

Pressure Differential

Pressure differential across the boundaries of the fire space were measured using low differential type pressure transducers (Setra Model 264) having a range of 0-0.9 Torr (0-0.5 in H_2O). The sensing points for these instruments were located on the center-line bulkhead at FR 17 122.0 cm (48 in.) above the deck, and on the center of the aft bulkhead 122.0 cm (48 in.) above the deck. In each case, the pressure differential was measured by connecting

the high side of the transducer to a sensing line that terminated inside the fire space, while the low side of the transducer was connected to a sensing line that terminated at the same relative position in the adjacent space (GSK and CIC aft respectively).

Firefighting, Damage Control and Protective Equipment

Standard Navy firefighting, damage control and protective equipment used in this test series included the following:

a. One-piece Navy firefighters ensemble (NSN 8415-01-300-6558) with DC/firefighters helmet (NSN84515-01-271-8069), anti-flash hood (NSN 8415-001-268-3473) and firefighter's gloves (NSN 8415-01-296-5766).

b. Fireman's rubber boots (NSN 8405-00-753-5940).

c. Type A-4 oxygen breathing apparatus (OBA) (NSN 4240-00-616-2857).

d. Oxygen breathing apparatus canisters (NSN 4240-00-174-1365).

e. Helmet lights (NSN 6230-01-285-4396).

f. Anti-flash gloves (NSN 8415-01-267-9661).

g. Type 1, 3.8 cm (1.5 in.) 360 Lpm (95 gpm) vari-nozzle IAW MIL-N-24408 attached to 3.8 cm (1.5 in.) fabric jacketed hose (NSN 4210-00-255-6234).

h. Chemlights (chemically activated markers) Model 95270-53 manufactured by American Cyanamid.

i. Smoke curtains (NSN 4210-01-306-7826).

j. Smoke curtain clamps (1H0000-LL-CGA-2487).

k. NFTI (NSN 4210-01-21307310).

In addition, gloves from NCTF were used in these tests. A 1.9 cm (0.75-in.) hoseline, described in [3] was also used for overhaul and mop-up operations.

Procedures

Prior to each test, the fire area was cleared of all personnel except designated safety team members. The ship's operational status during the tests was Level Ia [15]. The designated safety officer during these tests patrolled the forward section of the ship, primarily on the second deck. Two safety personnel were positioned aft of WTD 2-22-2 to pour and ignite the fuel and to keep watch on the fire while it burned. An additional safety team member was positioned in CIC aft to monitor the observers and assist in emergency evacuations. A final safety team member was stationed on the fo'c'sle with the corpsmen and medical group personnel to monitor normal movements of the attack team into and out of the second deck test area.

Prior to pouring fuel, the pretest check list was completed. The fire pump was brought on line at 827 kPa (120 psi). This resulted in a nominal flow rate at the vari-nozzle of approximately 360 Lpm (95 gpm). The proper ventilation configuration for the fire threat was aligned including fan settings and accesses to the spaces. Video recorders were started and data acquisition was initiated.

Once it was established that the data acquisition system was functioning properly, the test director gave the command to have fuel poured into the pans located beneath the cribs. Once fueling was completed, the fires were ignited and the fire was called away over the 1 MC system. This was the signal for the attack team to finish dressing out and report to the fo'c'sle. During this preburn period, fresh air to the fire space was throttled via WTD 2-21-2 to regulate the fuel burning rate.

It took an average 10 to 15 minutes for the attack team to get fully dressed out and staged at Repair 2. Once all attack team members were in place, WTD 2-21-2 was dogged. The attack team then proceeded from Repair 2, manned the already charged hoseline, and proceeded through GSK into the fire space. In all cases, the fire was fought using the 3.8 cm (1.5 in.) handline equipped with the 360 Lpm (95 gpm) nozzle. All attack team members wore full protection using Navy firefighters ensembles.

For the offensive fog attack method, the attack team entered the fire compartment approximately 1.2 to 1.8 m (4 to 6 ft), took a crouched or semi-crouched position, set the vari-nozzle to the 60° fog pattern, and discharge the stream upwards at a 45° angle into the flaming overhead in front of them. A series of two or three short bursts, 2-3 seconds in duration was generally sufficient to achieve fire knockdown. The tactics for the traditional straight stream were identical except that the nozzles was set on the straight stream or 30° angle position. Initially the nozzlemen did not throttle the flow rate by opening the bail handle only partially, but after being reminded of this tactic it was incorporated into subsequent evolutions.

The attack teams actions for each of the tests are described in Section 8. The control room had continuous WIFCOM reports from an observer in the fire compartment for the duration of all tests.

EXPERIMENTS CONDUCTED

Table 3 lists the firefighting tests conducted during the period 12-16 September, 1994. The initial six tests were conducted to evaluate and compare the two firefighting tactics on a growing/steady state fire with obstructions (Fire Threat No. 1). The next two tests were conducted to evaluate the impact the obstructions had on the tactics. The growing/steady state fire was used again, but for these tests the obstructions were removed (Fire Threat No. 1A). The final test was conducted with the "low visibility" fire scenario (Fire Threat No. 2).

Table 3. 1994 Attack Team Workshop Firefighting Tests

Date	Test No.	Test Team	Fire Threat	Obstructions	Firefighting Tactic
9/12/94	FOG-12	RUSSELL	Growing/Steady State (No. 1)	Yes	Traditional Straight Stream
9/13/94	FOG-13	All Female	Growing/Steady State (No. 2)	Yes	Aggressive Fog
9/13/94	FOG-14	PEB	Growing/Steady State (No. 1)	Yes	Traditional Straight Stream
9/14/94	FOG-15	RUSSELL	Growing/Steady State (No. 1)	Yes	Aggressive
9/14/94	FOG-16	All Female	Growing/Steady State (No. 1)	Yes	Traditional Straight Stream
9/15/94	FOG-17	PEB	Growing/Steady State (No. 1)	Yes	Aggressive Fog
9/15/94	FOG-18	RUSSELL	Growing/Steady State (No. 1A)	No	Traditional Straight Stream
9/16/94	FOG-19	All Female	Growing/Steady State (No. 1A)	No	Aggressive Fog
9/16/94	FOG-20	PEB	Low Visibility (No. 2)	No	Aggressive Fog

Table 4 lists the ancillary research and evaluation performed concurrent with the firefighting tests. These tasks ranged from the very specific, with dedicated instrumentation (e.g., heat stress tests) to qualitative evaluations. In some cases, data

Table 4. Attack Team Workshop Participants

Organization	Program Manager/Lead Personnel	Activity
Naval Health Research Center	Donald Hagen, Ph.D. Kim Williams, Ph.D.	Heat Stress Psychological Studies
NCTRF	Richard Wojtaszek	Gloves/Protective Equipment
CINCPACFLTPEB	CAPT Condon CDR Dennis LCDR Guido	Observer Observer PEB Attack Team Leader
CINCLANTFLTPEB	LCDR Wilkins	Female Attack Team Leader
RUSSELL	DCC Michael Lane	Attack Team DCC
ARPA/MSTO	CAPT Lowell	Observer
NDI	DCCM Wheelwright	NDI Equipment
SWOS	LT Pickel	Safety
NAVSEA 03G	Hank Kuzma David Satterfield Dennis McCrory	DC Firefighting Doctrine Protective (Equipment) Breathing Apparatus

Other participating organizations: ATG MIDPAC
USS EMORY S LAND
FTC Treasure Island (A School)
IDA
MPR Associates
CD/NSWC
JHU/APL
Global Associates

from the fire test instrumentation was used to provide correlating data. Persons interested in the specifics of any particular evaluation are encouraged to contact the researchers, engineers, or program managers listed.

RESULTS OF FIREFIGHTING TESTS

Fire Threat Repeatability

As was described previously, it was important that the fire threat developed for these tests be repeatable from test to test. Maintaining this repeatability proved to be a challenging task because the fresh air supply to the fire space had to be regulated by controlling how far watertight door WTD 2-21-2 was opened. The most reliable indicator of repeatability for these fires was the average overhead temperatures for the fire space. These values were also the most pertinent because the hot gases and flames in the overhead were one of the primary challenges for the attack team.

Table 5 presents average overhead temperature data at various time steps for tests FOG__12 through FOG__19. These tests all used Fire Threat No. 1 or No. 1A, which are essentially the same fire threat with and without the obstructions. The interval from 5 to 10 minutes was chosen because this represents the true growth period of the fire, after the initiating fuel has burned out. Based on the data presented in Table 5, the repeatability was very good. Mean values for all tests are presented, along with the standard deviations. The standard deviations are in the range of 2-7% of their respective mean values, indicating good repeatability of the fire threat as characterized by average overhead temperatures.

The data presented in Table 5 also confirms that for all tests, the goal of providing a fire that was at or near flashover was achieved. All average temperatures are above 500°C (932°F), and at the 12 minute mark, 6 of the 8 tests had average overhead temperatures in excess of 600°C (1112°F). While these values tended to be less at the time of entry into the compartment, qualitative observations of the attack team and safety team members in the fire space confirmed that there was flaming in the overhead in all cases.

Table 5. Average Overhead Temperatures at Various Times

Test No.	Fire Threat	Maximum Temperature (°C (°F)) for 5-10 Minute Interval	Temperature (°C (°F)) @ 12 Minutes	Time of Entry Into Compartment (min)	Temperature (°C (°F)) at Time of Entry
FOG-12	1	615	585	15:30	583
FOG-13	1	586	604	14:48	541
FOG-14	1	590	622	14:57	517
FOG-15	1	601	655	13:23	647
FOG-16	1	593	602	12:37	590
FOG-17	1	602	595	13:33	587
FOG-18	3	595	632	12:07	631
FOG-19	3	579	620	13:03	632
Mean ($\bar{x}$)		595	614	13:45	591
Std. Dev. ( )		10	21	1:00	43

General Results of Firefighting Evolutions

Measures of Performance

In order to compare the test results, measures of performance to evaluate heat, steam, and fire threat experienced by the attack team, as well as the water usage were developed. The analysis of the Phase I Scoping tests data [13] indicated that wood crib thermocouples, overhead and string thermocouples, calorimeters, pressure transducers, and flowmeters all provided measures of performance in the medium scale tests. The Phase II test plan [14] lists the measurements considered important for the full scale tests. Of the six measurements identified, five proved to be useful.

The five measurements determined to best demonstrate the effectiveness of a given attack method were as follows:

(1) Wood crib thermocouples:

(2) Average of overhead thermocouples in the fire space;

(3) Upper vs. lower calorimeter (total heat flux) in the fire space;

(4) Average of upper three string thermocouples vs. Average of lower three string thermocouples for strings in the fire space; and,

(5) Cumulative total water used.

The wood crib thermocouples showed when the fire was knocked down, when it flared up, and when it was finally extinguished. One thermocouple from each wood crib was selected for reporting based on the data it showed and it's correlation with recorded events.

The average overhead temperatures showed the thermal threat existing in the overhead and how well it was controlled. This data also provided an indication of when reflashes occurred.

The calorimeter and thermocouple string data demonstrated how much the thermal balance within the fire compartment was disturbed. For the Phase I scoping tests, the thermocouple string data did not show the disturbance in the thermal balance nearly as well as the calorimeters. However, for the full-scale tests, the correlation between the calorimeter and thermocouple string data was better.

The pressure transducer data was not included as a measure of performance because the units were out of service for most of the tests.

General Results of Firefighting Tests

The results of the Phase II firefighting tests are documented in this section. The principal variables for each test were identified in Table 3. For each test, there is a brief description of the evolution, a timeline of events, and data graphs showing the measures of performance. Representative data for all data channels are given in Appendix B.

FOG-12

This test was performed using the traditional straight stream tactic. The attack team was comprised of personnel from the Precommissioning Unit of the RUSSEL. Fire Threat No. 1 was used. The hoseline was manned and entry was made at 15:30 after ignition. Fire conditions at that time were reported to be a homogeneous smoke layer with flames visible in the overhead.

The initial attack consisted of three short bursts with a narrow angle fog directed off the overhead and bulkheads. This resulted in heavy steam conditions with minimal or no control of the fire and steam burns to the team leader's and nozzleman's wrists. As the attack team backed out, the team leader lost his OBA seal and had to be replaced by the hoseman. The fire compartment was then fully involved.

A second attack was attempted from the doorway. A single burst with a narrow angle fog darkened down the fire enough for the attack team to attempt re-entry, but steam conditions and reflashes forced them back to the doorway where six more bursts knocked down continuing reflashes. The nozzleman was relieved and five more bursts from the doorway, mostly directed at the overhead or bulkheads in an attempt to deflect water past the obstructions, were unable to control the reflashes. The nozzleman was relieved again and two more attempts were made from the doorway to control the fires, with similar results. At 24:42 minutes:seconds after ignition, the safety team relieved the attack team and the evolution was terminated. Table 6 shows the sequence of events for this test while Figs. 12 and 13 present the measures of performance data.

Table 6. - Timeline of Events for FOG_12

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-15:30	Ignition, Fire Party Called Away	0 (0)
	Attack Team Enters Fire Compartment, Observes Flaming in Overhead Homogeneous Smoke Layer (0:00)	0 (0)
0:00	Initial Attack, Short Burst With Narrow Angle Fog (0:22)	19 (5)
	Fire Reflashes, Smoke Appears Heavier (0:36)	
	Short Burst (x2) at Reflash, Steam Down to 0.9m (3 ft) Level (0:42)	42 (11)
1:00	Fire Reported Out, Heavy Steam Conditions, Attack Team Backing Out (1:02)	
	Attack Team Out of Compartment (1:14)	
2:00	Fire Reported Still Burning (1:27)	
	Attack From 0.3-0.6m (1-2 ft) Inside Doorway, Short Burst (2:35)	57 (15)
3:00	Attack Team Reports Fire Darkened Down, Entering to Investigate (3:03)	
	Attack Team Backs Out to Doorway, Attacks Reflash in Fire Area #1, Short Burst (3:53)	79 (21)
4:00	Attack From Doorway (4:23)	91 (24)
	Fire Reflashes, Attack From Doorway (x2), Attack Team Then Reports No Visible Flame (4:48)	110 (29)
5:00	Fire Area #3 Reflashes, Attack From Doorway (x2) (5:13)	136 (36)
	Change Nozzleman, Attack From Doorway, Short Burst (x2) (5:50)	163 (43)
6:00	Fire Still Burning in Fire Areas #1 and #3. Attack From Doorway With Narrow Angle Fog, Short Burst (x3) (6:53)	193 (51)
7:00		
8:00	Team Leader Takes Over Nozzle (8:06)	
	Attack From Doorway, Short Burst (x2) (8:20)	238 (63)
9:00	Attack Team Relieved by Safety, Safety Extinguishes Remaining Fire (9:12)	
10:00		
11:00		
12:00	Fire Declared Out, Space Vented Using E1-15-2 (12:03)	314 (83)
13:00		
14:00		

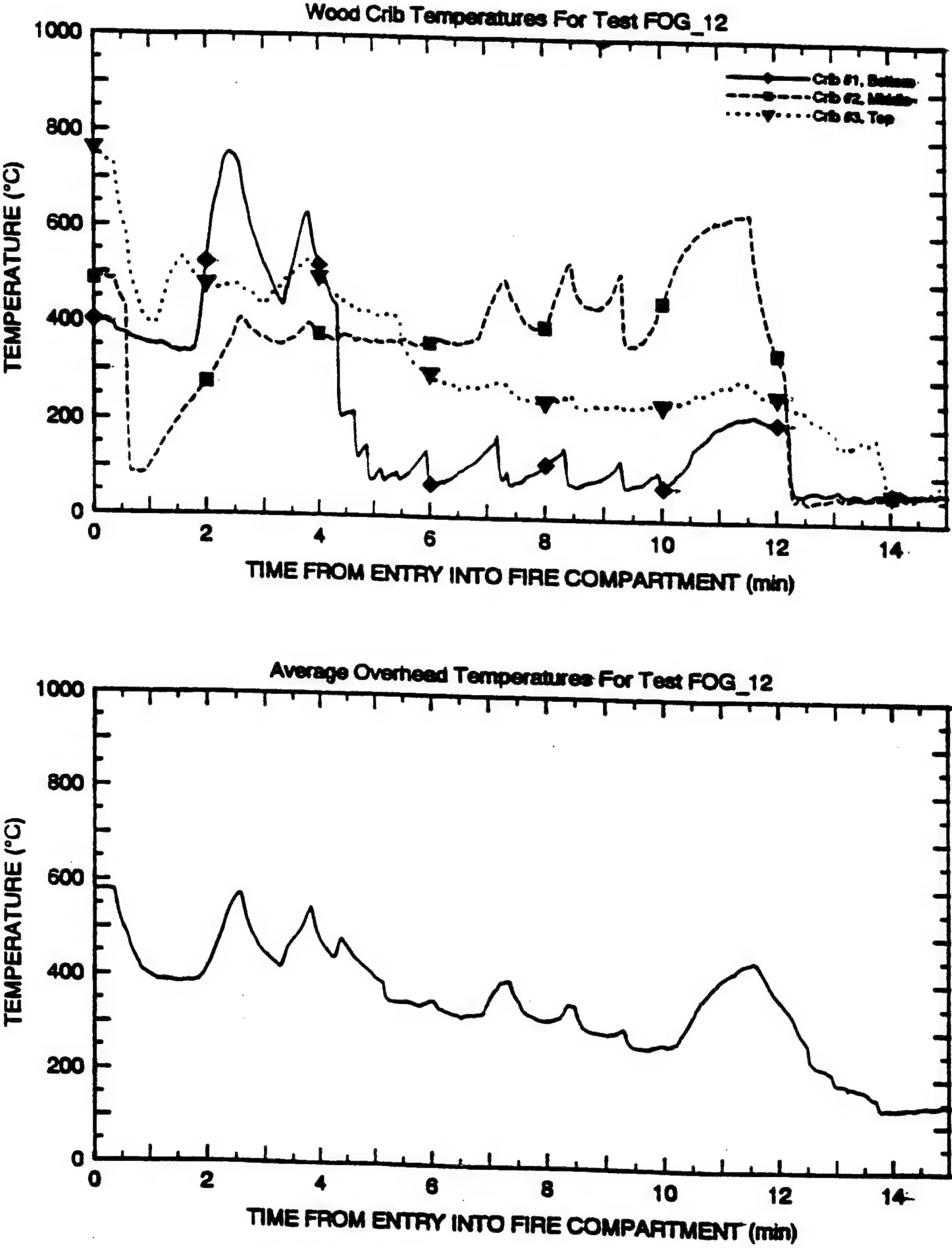
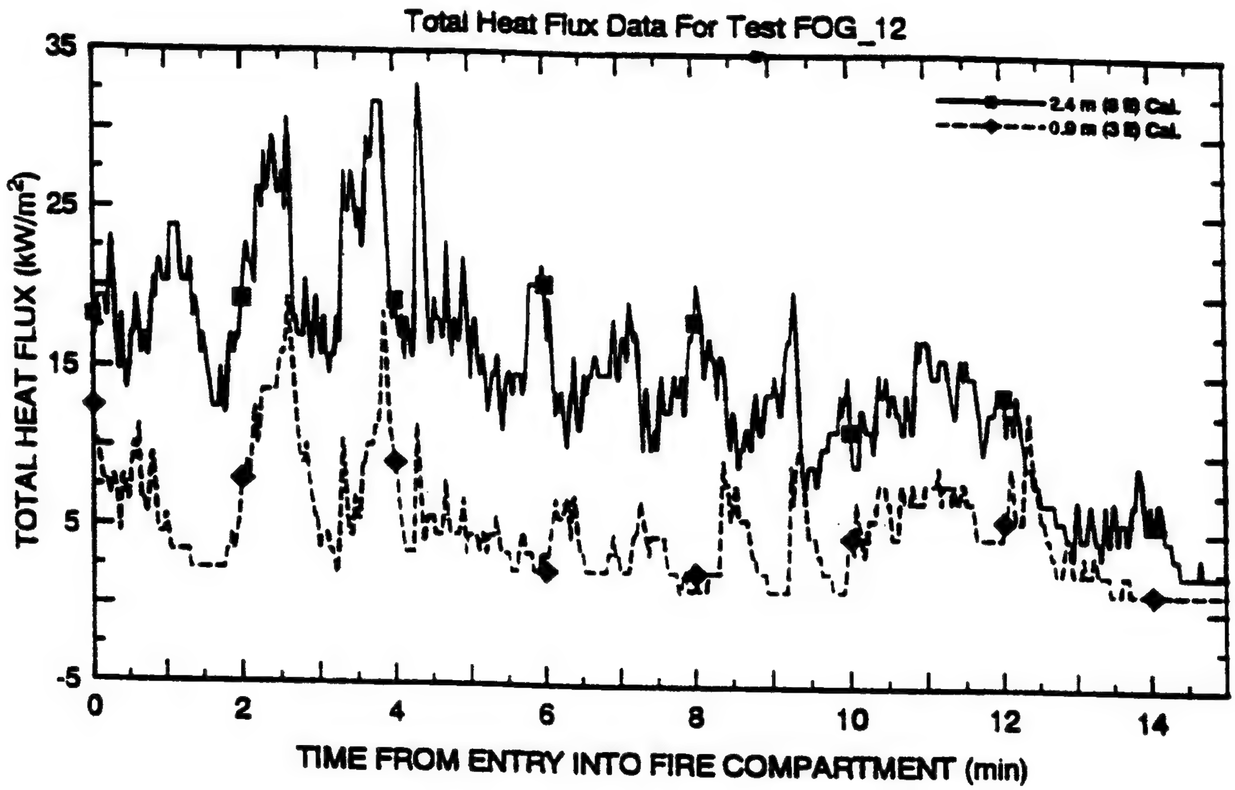


Fig. 12 - Wood crib and average overhead temperatures for FOG_12



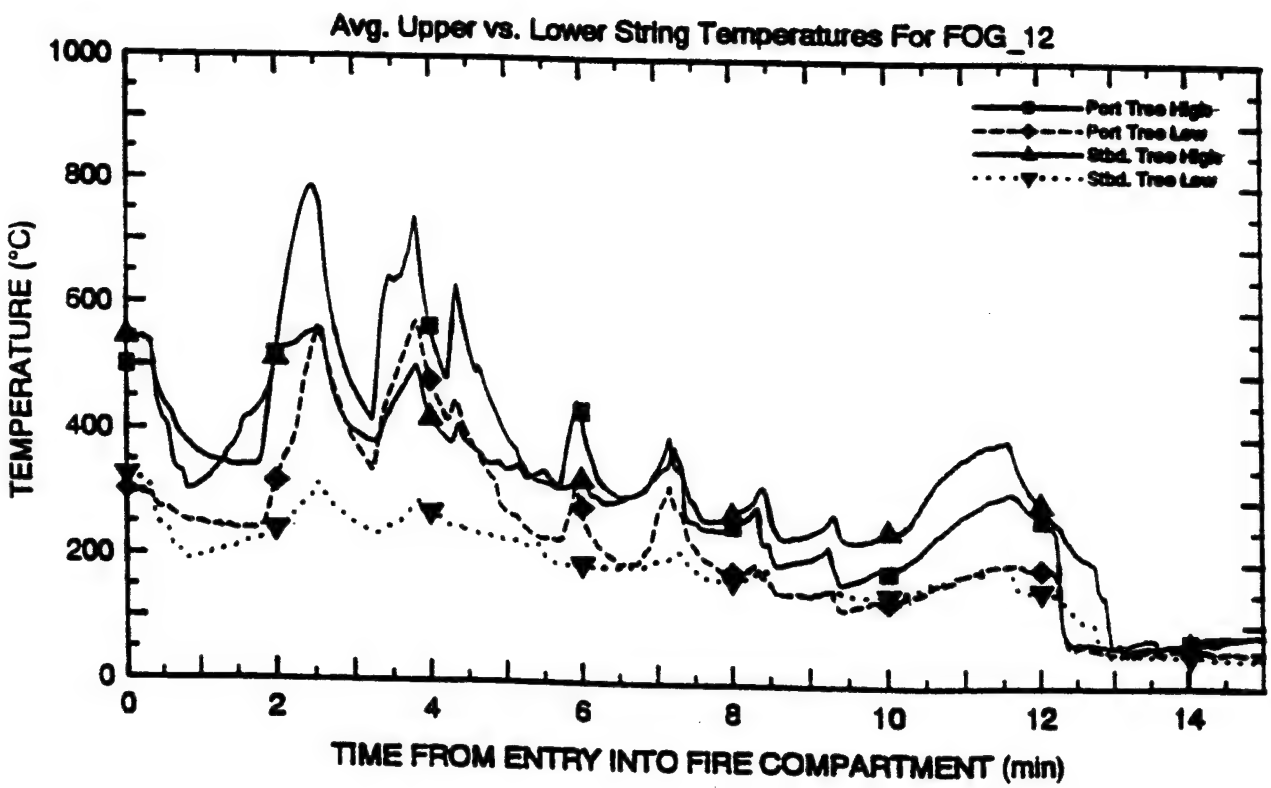


Fig. 13 - Total heat flux and average string temperatures for FOG_12

FOG_13

This test was performed using the offensive fog tactic. The attack team was comprised of personnel from the all-female team. Fire Threat No. 1 was used. The hoseline was manned and entry was made at 14:48 after ignition. Fire conditions at that time were reported to be reduced visibility with fire in the overhead and a slight thermal challenge.

The initial attack consisted of three short bursts with a medium angle fog directed 45° toward the overhead. This knocked down the fire enough that the attack team was able to move forward for a straight stream attack on the seat of the fire. A total of eight bursts were used on all three of the fire areas. This resulted in an increase in steam conditions, but no burns. During the straight stream attack, the team leader had to leave and was not immediately replaced. Without direction from the team leader and with steam conditions increasing, the attack team backed out to the doorway.

After regrouping, a medium angle fog attack at 45° angle in hot gas cloud of the fire compartment was performed from the doorway. The attack team reentered and used three short bursts of straight stream to knock down reflashes. Fire Area No. 1 reflashed again, forcing the attack team to back out. After a long burst from the doorway, the team members changed positions and reentered for a third attempt. After five more straight stream bursts at Fire Areas No. 1 and No. 2, the attack team backed out and safety took over. Fires were still burning in all fire areas. Table 7 shows the sequence of events for this test while Figs. 14 and 15 present the measures of performance data.

Table 7. - Timeline of Events for FOG_13

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-14:48	Ignition, Fire Party Called Away	0 (0)
0:00	Attack Team Enters Fire Compartment, Observes Reduced Visibility, Slight Thermal Challenge (0:00)	
	Initial Attack, 3 s Bursts (x3) With Medium Angle Fog (0:21)	19 (5)
1:00	Attack Team Advances to Fire Area #1, Direct Attack With Straight Stream, Slightly Longer Burst (0:57)	26 (7)
	Attack Team Advances to Fire Area #2, Direct Attack With Straight Stream, Short Bursts (x3) (1:28)	38 (10)
2:00	Attack Team Stands Up for Direct Attack on Fire Area #3, Direct Attack With Straight Stream, Short Bursts (x2) (1:39)	45 (12)
	Direct Attack With Straight Stream, Short Bursts (x2) (1:57)	57 (15)
	Attack Team Backs Out of Compartment (2:14)	
3:00	Attack Team Re-enters Compartment, Fog Attack From Doorway, 3-5 s Burst (2:50)	76 (20)
	Attack Team Reports No Visible Flames, Advances For Direct Attack (3:24)	
4:00	Direct Attack With Straight Stream, Short Bursts (x3) (3:32)	110 (29)
	Fire Area #1 Reflashes (4:00)	
	Attack Team Backs Out of Compartment Again (4:17)	
5:00	Attack From Doorway, Long Burst (4:31)	151 (40)
	Attack Team Members Change Positions (4:56)	
	Attack Team Re-enters Compartment (5:08)	
6:00	Direct Attack on Fire Areas #1 and #2, Straight Stream, 3-5 s Bursts (x5) (5:23)	257 (68)
7:00	Attack Team Backs Out of Compartment, Fire Still Burning in All Fire Areas (6:47)	
8:00		
	Attack Team Relieved by Safety, Safety Extinguishes Remaining Fire (8:27)	371 (98)
9:00		
10:00		
11:00		
12:00	Fire Declared Out, Space Vented Using E1-15-2 (12:27)	
13:00		
14:00		

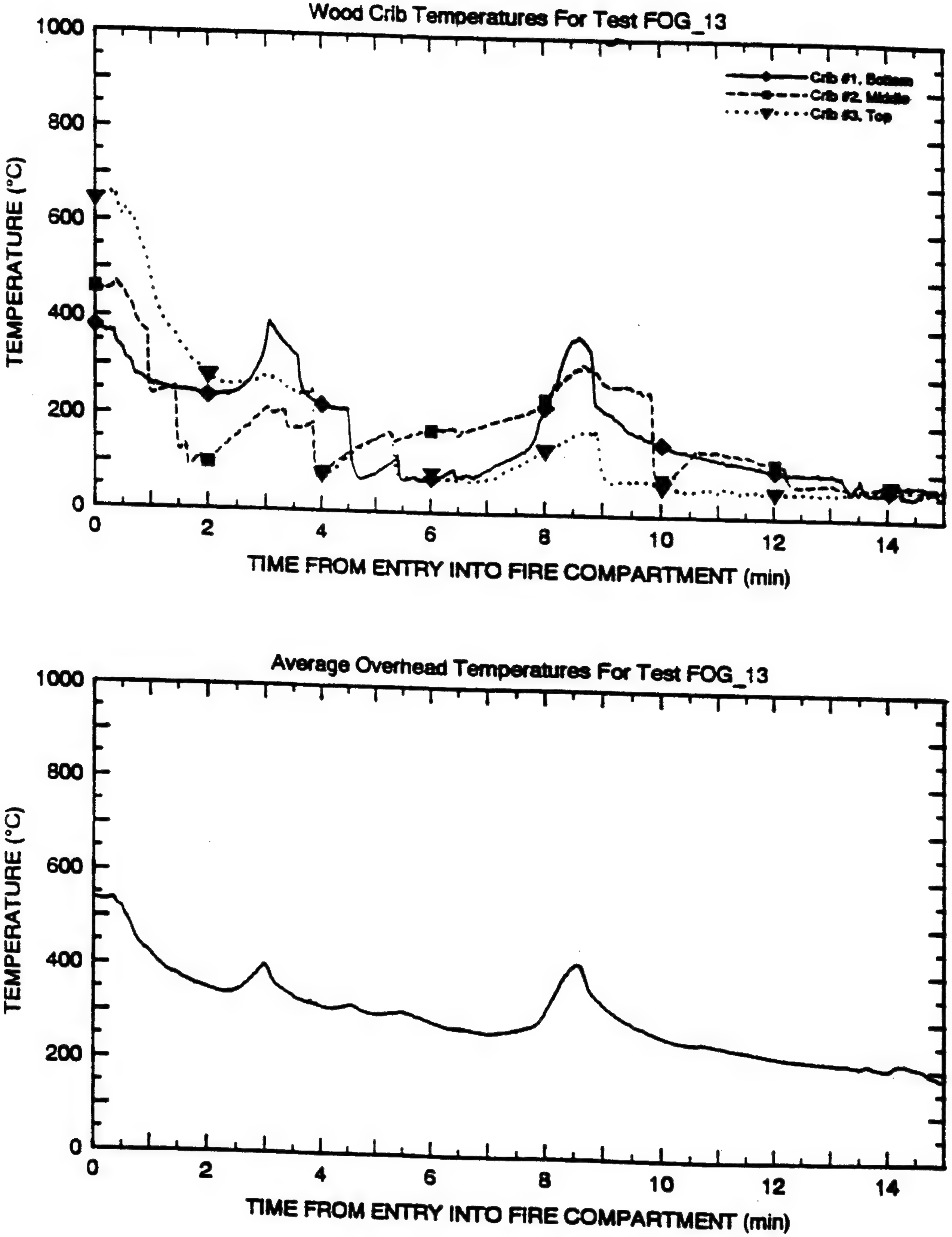
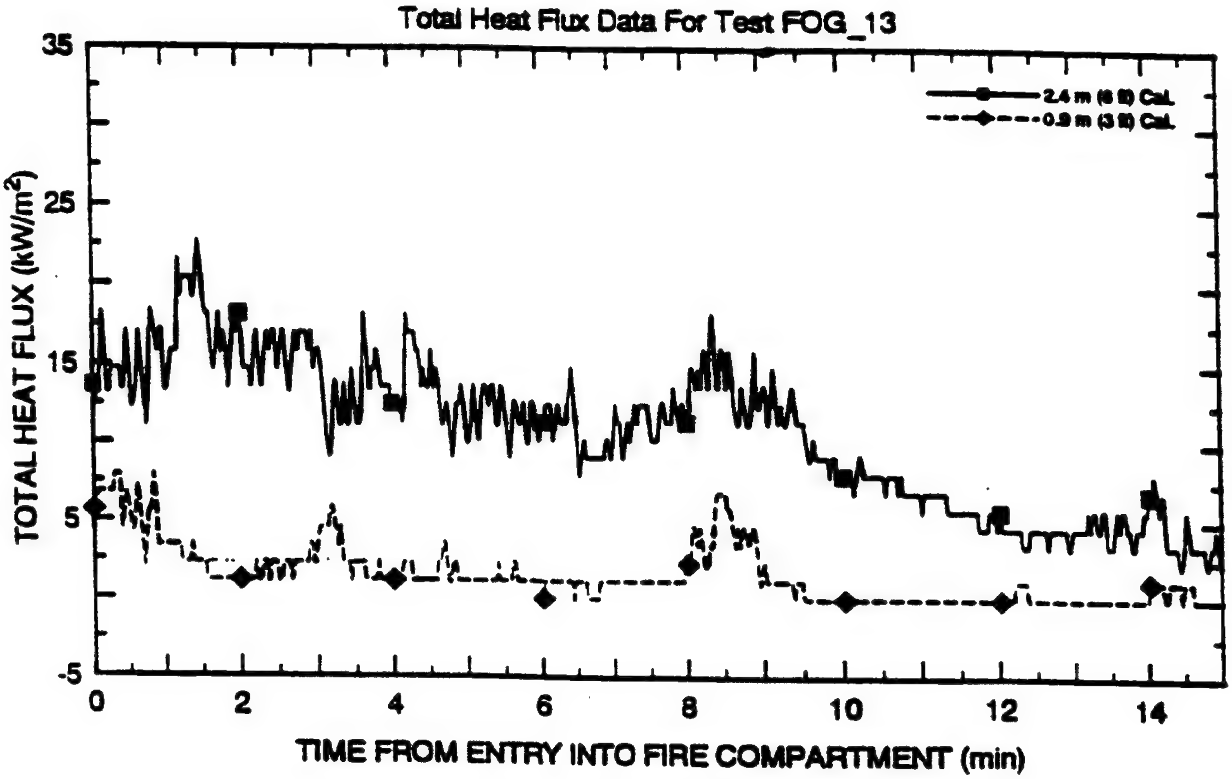


Fig. 14 - Wood crib and average overhead temperatures for FOG_13



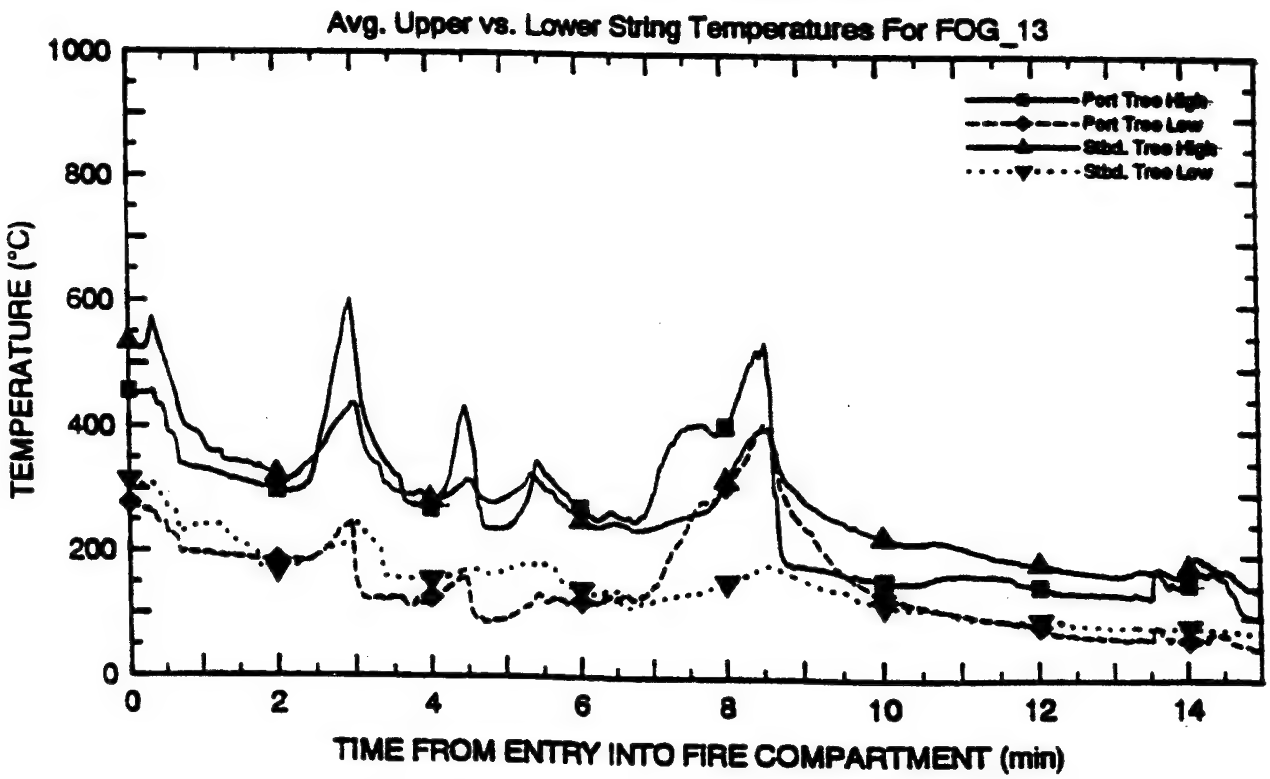


Fig. 15 - Total heat flux and average string temperatures for FOG_13

FOG_14

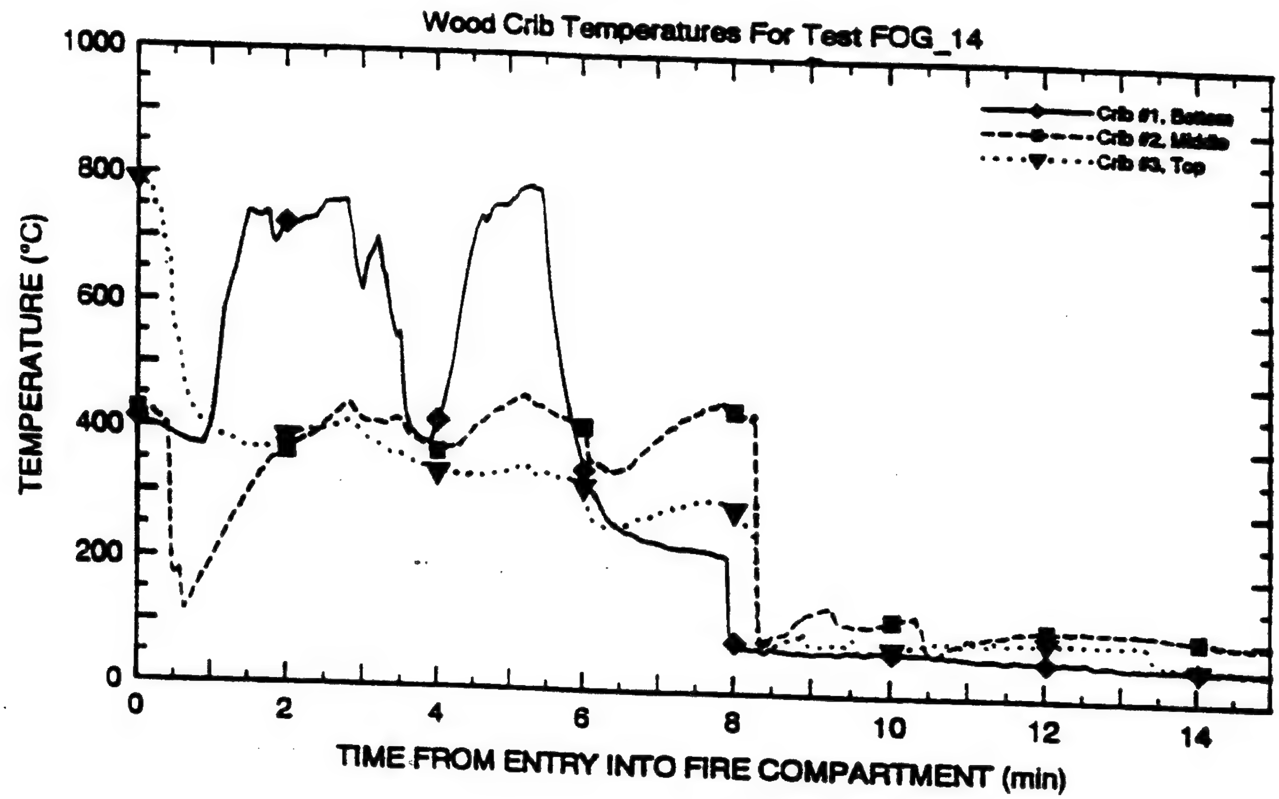
This test was performed using the traditional straight stream tactic. The attack team was comprised of PEB personnel. Fire Threat No. 1. The hoseline was manned and entry was made at 14:57 after ignition. Fire conditions at that time were not reported.

The initial attack consisted of two short bursts with a narrow angle fog. This resulted in heavy steam conditions and fire remained in the overhead. After three more short bursts, the attack team was able advanced to Fire Area No. 2. They stood up and attacked Fire Areas No. 2 and No. 3 with short bursts, but a reflash in Fire Area No. 1 and the overhead caused them to back off and attack Fire Area No. 1. After two short bursts they backed out to the doorway. All three fire areas were still involved.

A second attack was attempted from the doorway using three quick 3-5s bursts. These had minimal effect and with all fire areas still involved, the attack team reentered the compartment. They tried one burst and had to back out to switch nozzlemen. A third attack from the doorway consisting of four short bursts still had no effect on the fire. At 22:00 after ignition, the safety team relieved the attack team and the evolution was terminated. Table 8 shows the sequence of events for this test while Figs. 16 and 17 present the measures of performance data.

Table 8. - Timeline of Events for FOG_14

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-14:57	Ignition, Fire Party Called Away	0 (0)
	Attack Team Enters Compartment (0:00)	
	Initial Attack With Straight Stream, Short Bursts (x2), Steam Banked Down to 0.9m (2 ft) Level (0:11)	11 (3)
	Attack With Straight Stream, Short Bursts (x3), at Flames in Overhead (0:21)	23 (6)
	Attack Team Advances to Fire Area #2, Stands Up for Direct Attack (1:08)	
	Direct Attack on Fire Areas #2 and #3, Straight Stream, Short Burst, Fire Area #1 Reflashes (1:13)	30 (8)
	Attack Team Backs Off and Attacks Fire Area #1, Straight Stream, Short Bursts (x2) (1:48)	38 (10)
	Attack Team Backs Out of Compartment, All Three Fire Areas Still Involved (2:14)	
	Attack From Doorway, 3-5 s Bursts (2:50)	45 (12)
	Attack From Doorway, 3-5 s Bursts (x2) (3:19)	76 (20)
	Attack Team Re-enters Compartment, All Fires Still Burning (4:32)	
	Attack With Straight Stream, Short Burst (4:36)	83 (22)
	Attack Team Backs Out to Switch Nozzlemen, Fires Still Burning (5:03)	
	Attack From Door, Short Bursts (x4) (5:16)	106 (28)
	Fire Fighting Evolution Terminated, Attack Team Relieved by Safety (7:03)	
	Safety Extinguishes Remaining Fire (7:43)	273 (72)
	Fire Declared Out, Space Vented Using E1-15-2 (12:48)	



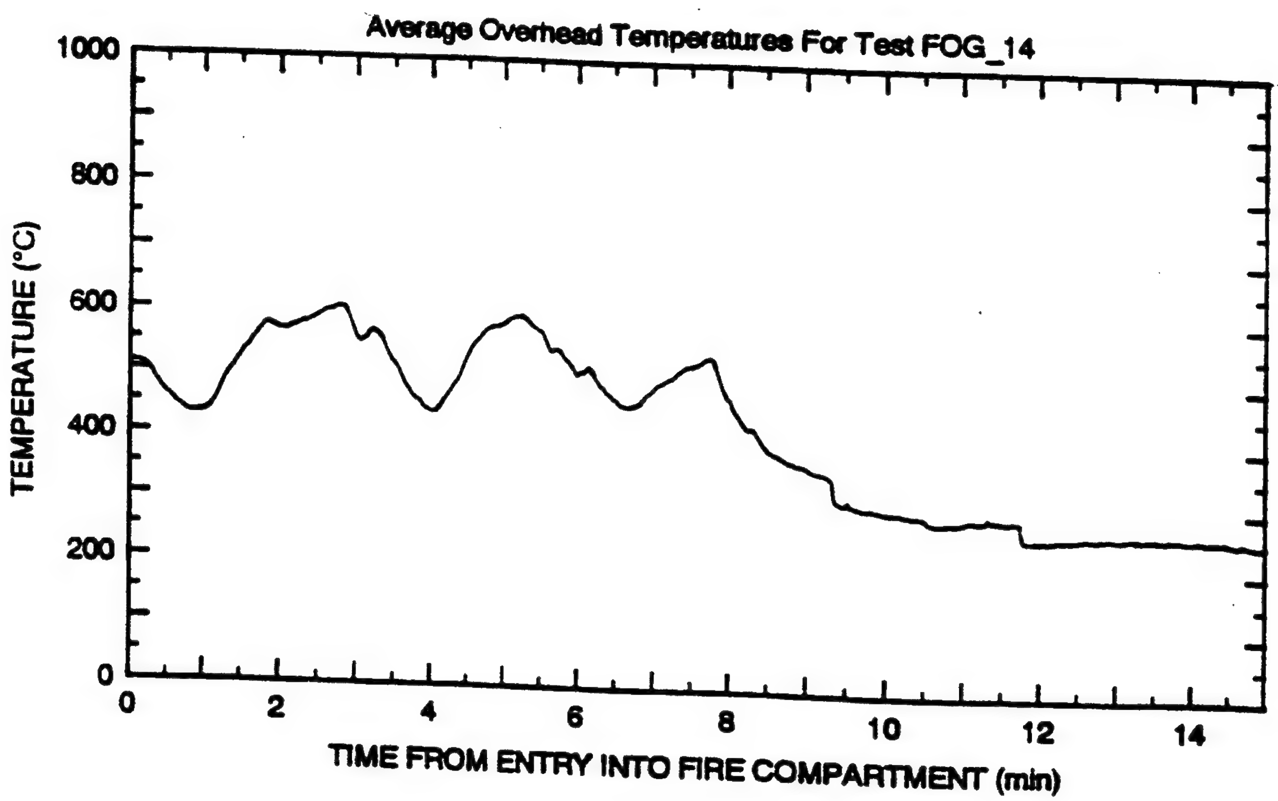


Fig. 16 - Wood crib and average overhead temperatures for FOG_14

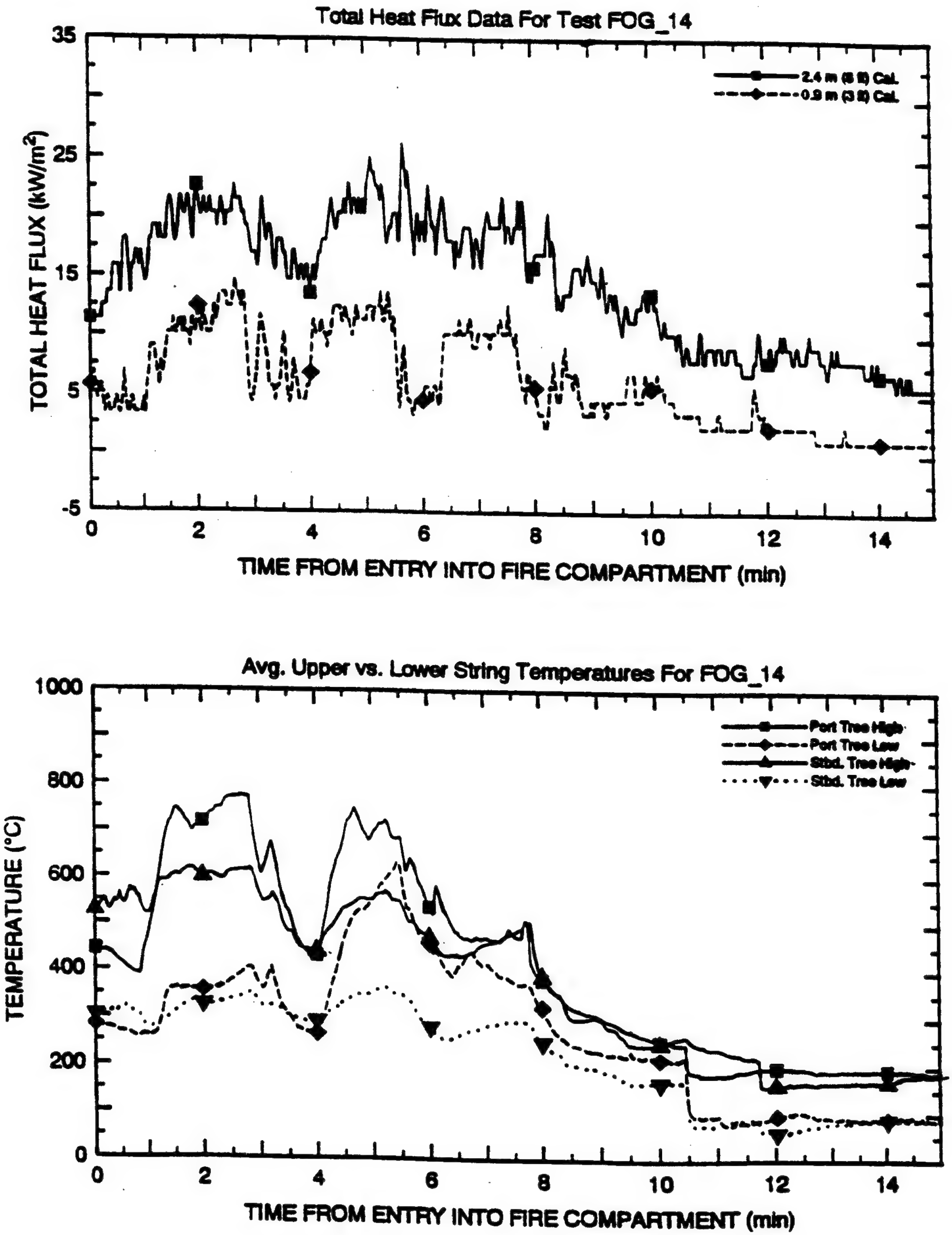


Fig. 17 - Total heat flux and average string temperatures for FOG_14

FOG_15

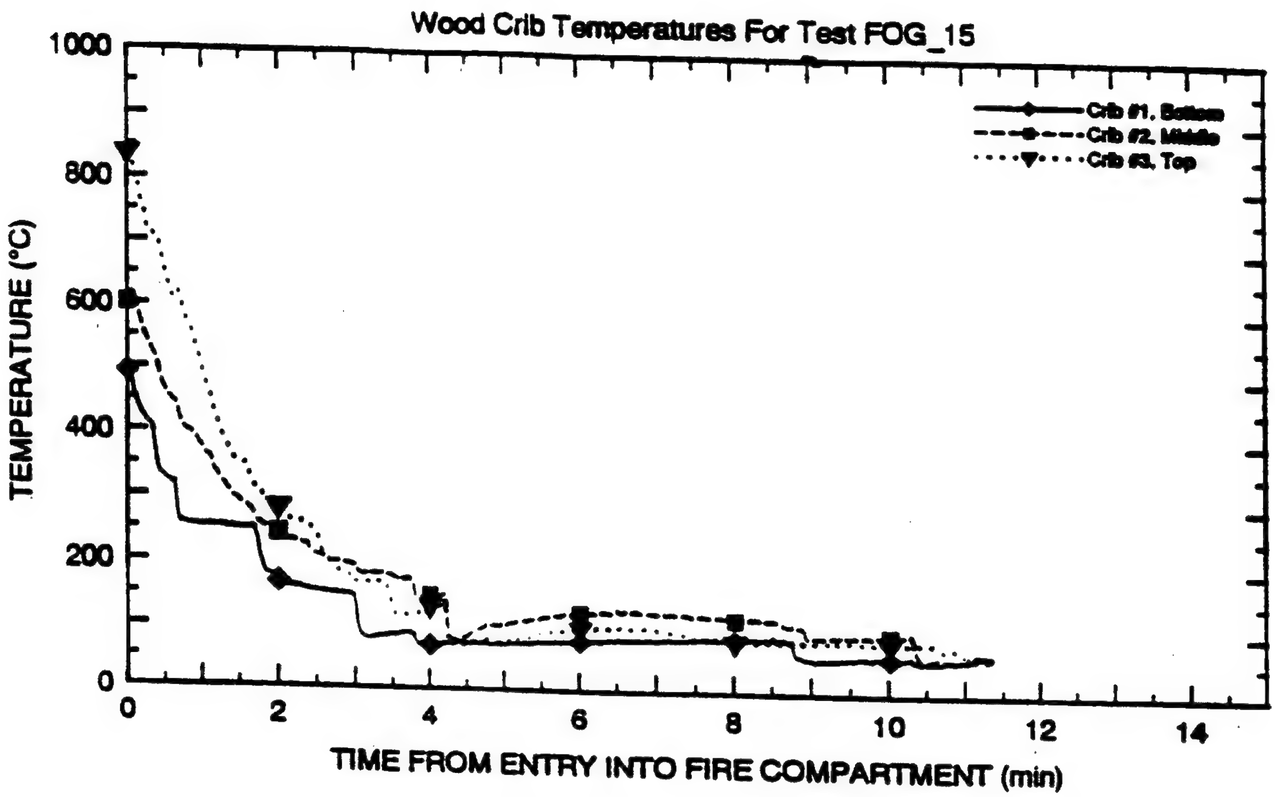
This test was a repeat of FOG_12, except that the offensive fog tactic was used. Entry was made at 13:23 after ignition. Fire conditions at that time were reported to be fire in the overhead, warm but not hot, and good visibility.

The initial attack consisted of three short 2-3s bursts with a medium angle fog directed at a 45° angle into the flames in the overhead. This resulted in steam banking down to the deck level, no flames were visible. Conditions were still tenable enough for the team to advance and attack the fire sources directly. After four bursts with a straight stream, the team changed nozzlemen. The original nozzleman had to leave the space at this time due to steam/heat stress. After two more longer bursts, the attack team reported no visible flaming and changed nozzlemen again. After attacking, rotating nozzlemen, and attacking one more time, the team stood up for final extinguishment.

Final extinguishment required four longer bursts (3-10s). At 19:31 after ignition, the safety team relieved the attack team and declared the fire out without having to use any further water. Table 9 shows the sequence of events for this test while Figs. 18 and 19 present the measures of performance data.

Table 9. - Timeline of Events for FOG_15

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-13:23	Ignition, Fire Party Called Away	0 (0)
	Attack Team Enters Fire Compartment, Good Visibility, Warm But Not Hot (0:00)	
	Initial Attack, Medium Angle Fog, 2-3 s Burst (0:02)	11 (3)
0:00	Fog Attack, 2-3 s Burst, Steam Banked Down to Deck Level, No Visible Flames (0:20)	26 (7)
	Fog Attack, 2-3 s Burst (0:39)	42 (11)
	Attack Team Advances into Space for Direct Attack (0:50)	
1:00	Direct Attack With Straight Stream, Short Bursts (x2) (0:54)	64 (17)
	Direct Attack, 3-5 s Bursts (x2) (1:04)	106 (28)
	Attack Team Rotates Positions, Original Nozzleman Leaves Space (1:19)	
2:00	Direct Attack, 5-10 s Burst Followed Immediately by 3-5 s Burst (1:39)	174 (46)
	Attack Team Reports No Visible Flames, Changing Nozzleman (2:01)	
3:00	Direct Attack, 5-10 s Burst (2:24)	208 (55)
	Attack Team Rotates Positions Again, Direct Attack, 5-10 s Burst (2:59)	
4:00	Attack Team Stands Up For Final Extinguishment, Direct Attack, 5-10 s Burst Followed by 3-5 s Burst (3:34)	326 (86)
	Attack Team Establishes Reflash Watch (4:04)	
	Direct Attack on Fire Area #3, 2-3 s Burst (4:14)	341 (90)
5:00	Direct Attack on Fire Area #3, 3-5 s Burst (4:54)	383 (96)
6:00	Attack Team Exits Compartment, Safety Takes Over Final Overhaul (6:08)	
	Fire Declared Out, Space Vented Using E1-15-2 (6:37)	
7:00		
8:00		
9:00		
10:00		
11:00		
12:00		
13:00		
14:00		



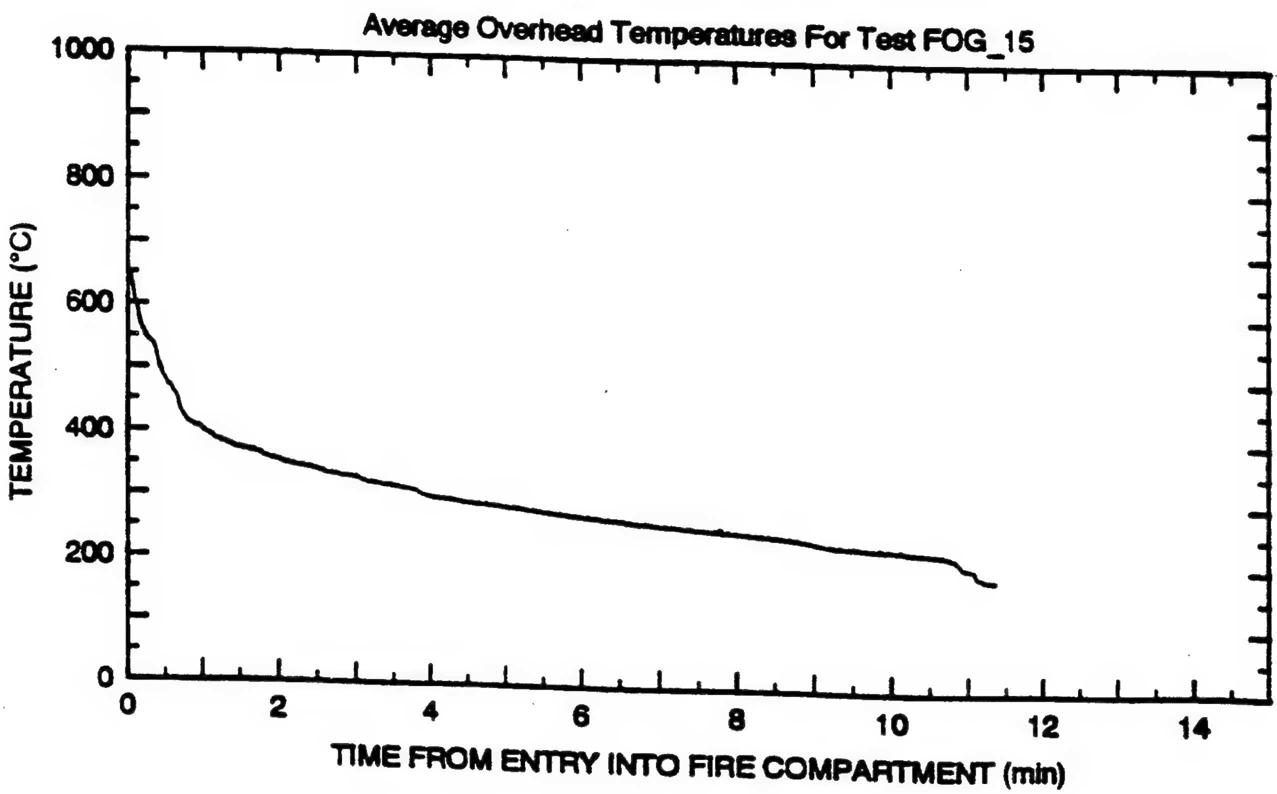
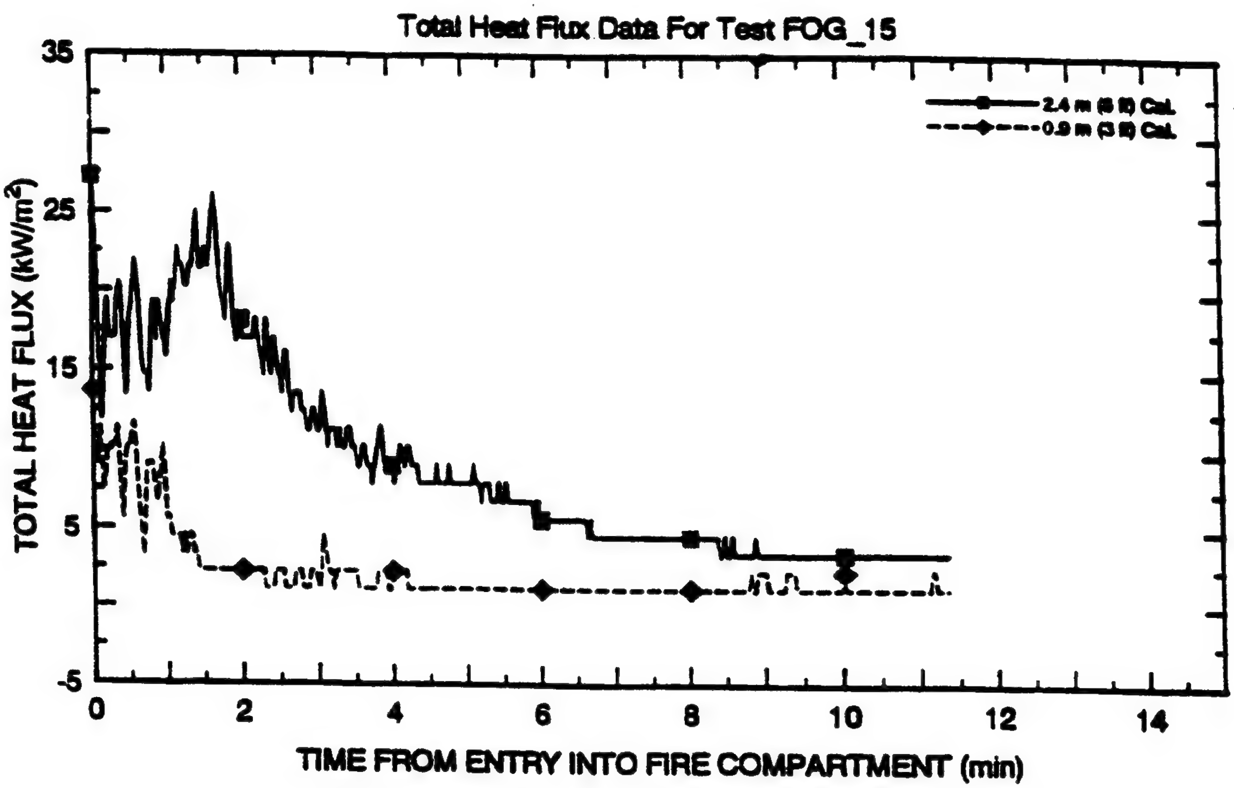


Fig. 18 - Wood crib and average overhead temperatures for FOG_15



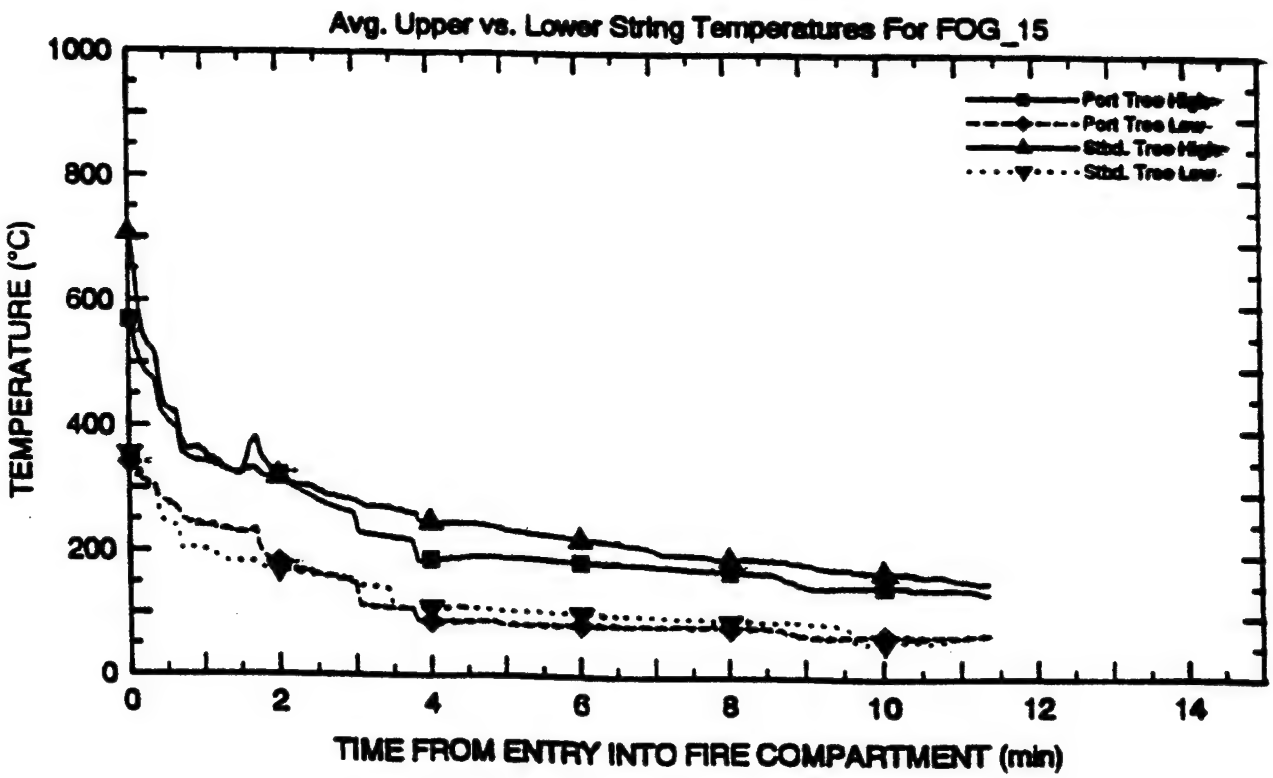


Fig. 19 - Total heat flux and average string temperatures for FOG_15

FOG_16

This test was a repeat of FOG_13, except that the traditional straight stream tactic was used. Entry was made at 12:37 after ignition. Fire conditions at that time were reported to be fire in the overhead, but not much heat and good visibility.

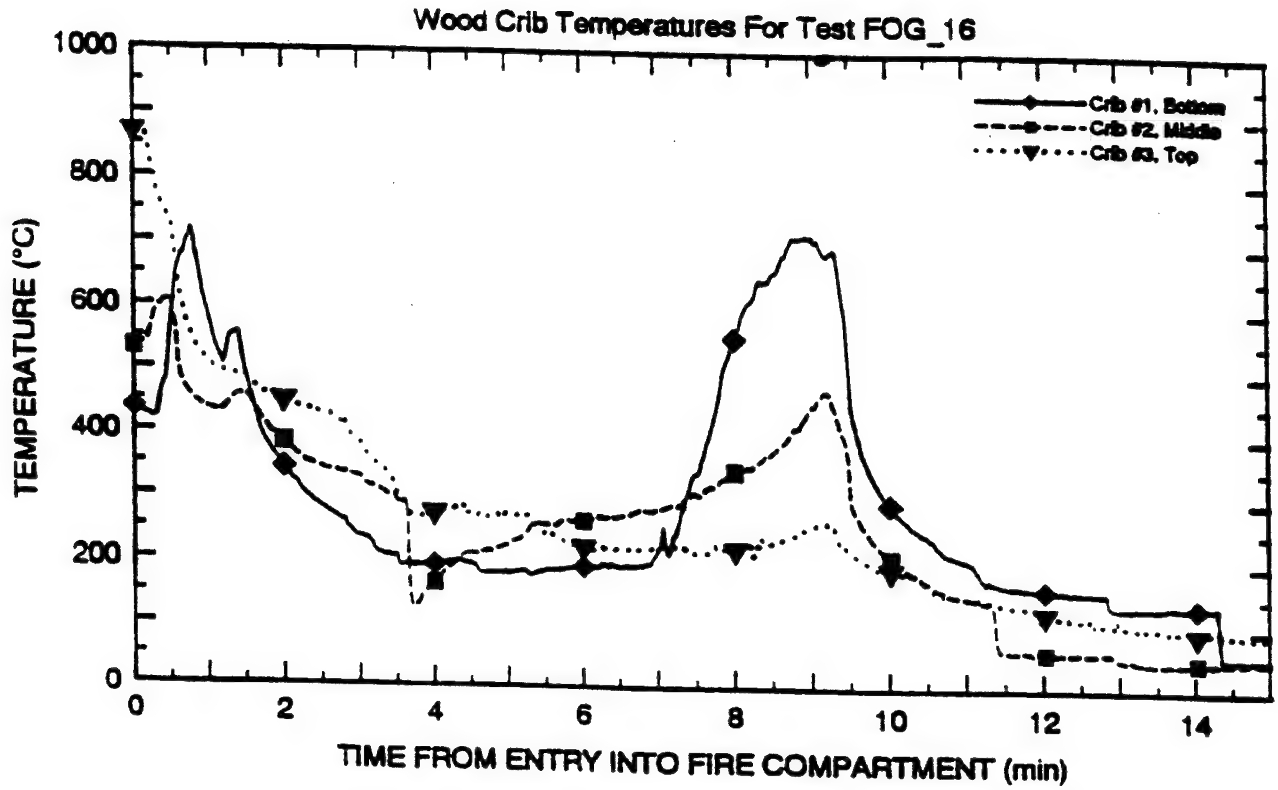
The initial attack consisted of a 3-5s burst with a narrow angle fog. This managed to knock down the fire in Fire Areas No. 2 and No. 3, but fire remained in the overhead and steam conditions were significantly increased. A short burst was directed at Fire Area No. 1 and then the attack team had to back out of the compartment.

After personnel were repositioned on the hoseline, a second attack was attempted from the doorway. After two short bursts, the team again backed out. The attack team repositioned on the hoseline once more, and the team leader had to be relieved. Six bursts from the doorway were still unable to control the continued reflashes. The attack team attempted to reenter the space, but was forced back out by the heat and steam conditions. After four more bursts from the doorway, another attempt was made to reenter the space. Two short bursts from inside the doorway were unable to control the fire and the attack team had to back out again. At 21:14 minutes:seconds after ignition, the safety team relieved the attack team, ending the evolution with the compartment fully involved. Table 10 shows the sequence of events for this test while Figs. 20 and 21 present the measures of performance data.

Table 10. - Timeline of Events for FOG_16

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-12:37	Ignition, Fire Party Called Away	0 (0)
0:00	Attack Team Enters Compartment, Advances 0.9-1.2m (3-4 ft) Inside Doorway, Reports Good Visibility, Not Much Heat (0:00)	
	Initial Attack With Straight Stream, 3-5 s Burst Knocks Down Flames in Fire Areas #2 and #3 (0:32)	15 (4)
	Attack Team Reports Fire in Overhead, Heavy Steam Conditions (0:37)	
	Attack On Fire Area #1, Short Burst (0:48)	26 (7)
	Attack Team Backs Out of Compartment, Repositions Handline (1:03)	
	Attack From Doorway, 3-5 s Burst, Then Another Short Burst (1:22)	38 (10)
	Attack Team Re-enters Compartment For Direct Attack (1:52)	
	Attack With Straight Stream, Short Bursts (x2) (2:02)	45 (12)
	Attack Team Backs Out of Compartment, Team Leader Requests Relief (2:28)	
	Attack Team Repositions on Handline, Attacks From Doorway With Straight Stream, Short Burst (2:53)	49 (13)
	Reflash in Fire Area #1, Attack From Doorway With Straight Stream, Short Bursts (x5) (3:09)	68 (18)
	Attack Team Reports Fire Still Burning in Fire Areas #1 and #3 (3:57)	
	Attack Team Attempts to Re-enter Compartment, Forced Out (4:11)	
	Attack From Doorway, 10-15 s Burst, Low Flow (4:21)	87 (23)
	Attack From Doorway, 10-15 s Burst, Low Flow (5:17)	95 (25)
	Attack From Doorway, 5-10 s Burst, Low Flow (5:39)	102 (27)
	Attack From Doorway, Short Bursts (x2) (6:03)	110 (79)
	Attack Team Re-enters Compartment (6:57)	
	Attack With Straight Stream, Short Bursts (x2) (7:04)	128 (34)
	Attack Team Exits Fire Compartment Final Time, Relieved By Safety, Fire Compartment Still Fully Involved (8:37)	
	Safety Team Re-enters Fire Compartment, Extinguishes Fire (8:53)	447 (118)
	Fire Declared Out, Space Vented Using E1-15-2 (13:23)	

Time axis: -12:37, 0:00, 1:00, 2:00, 3:00, 4:00, 5:00, 6:00, 7:00, 8:00, 9:00, 10:00, 11:00, 12:00, 13:00, 14:00



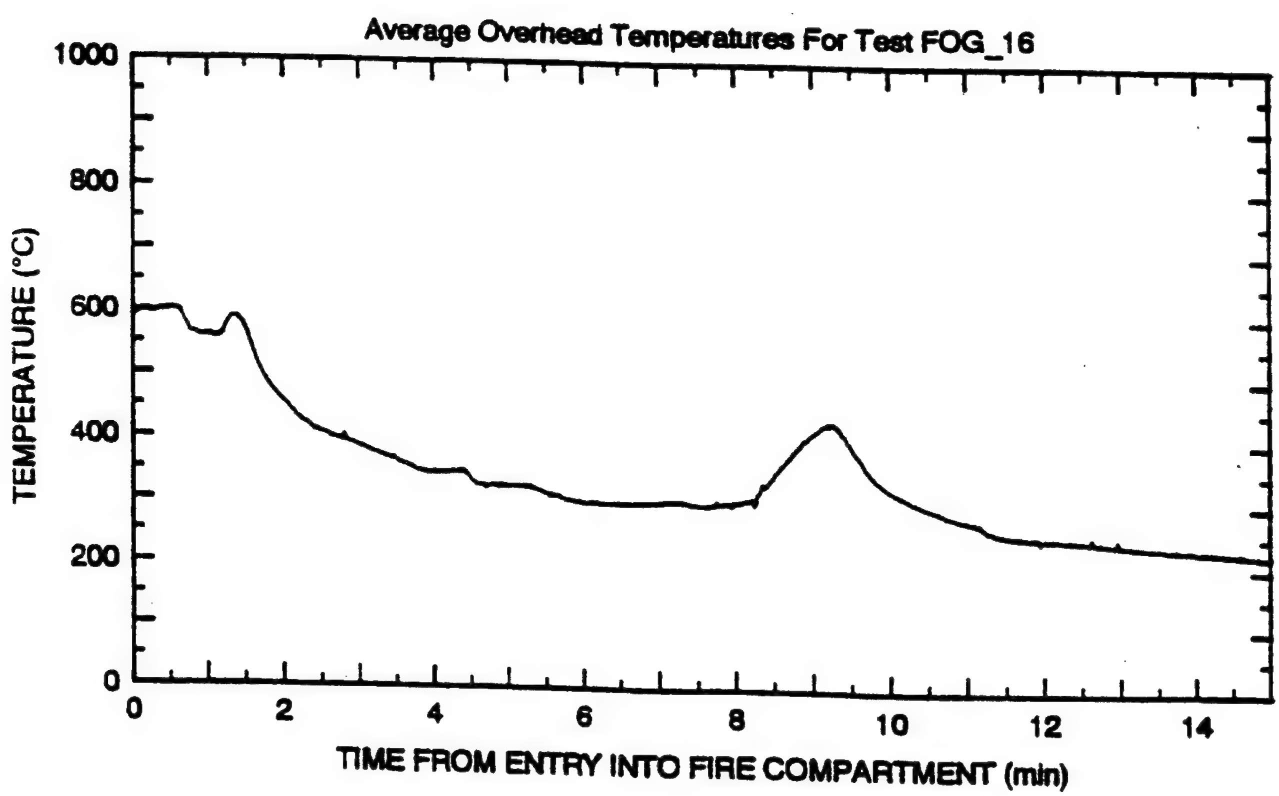
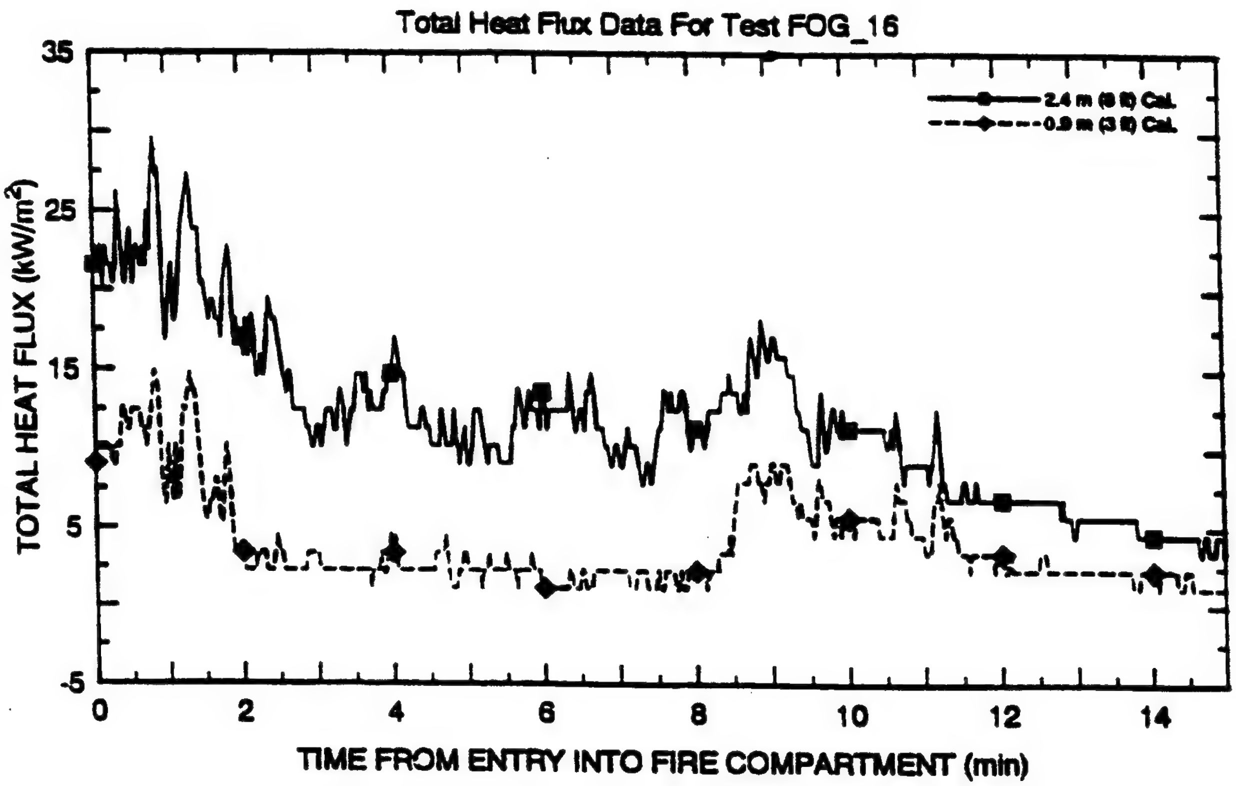


Fig. 20 - Wood crib and average overhead temperatures for FOG_16



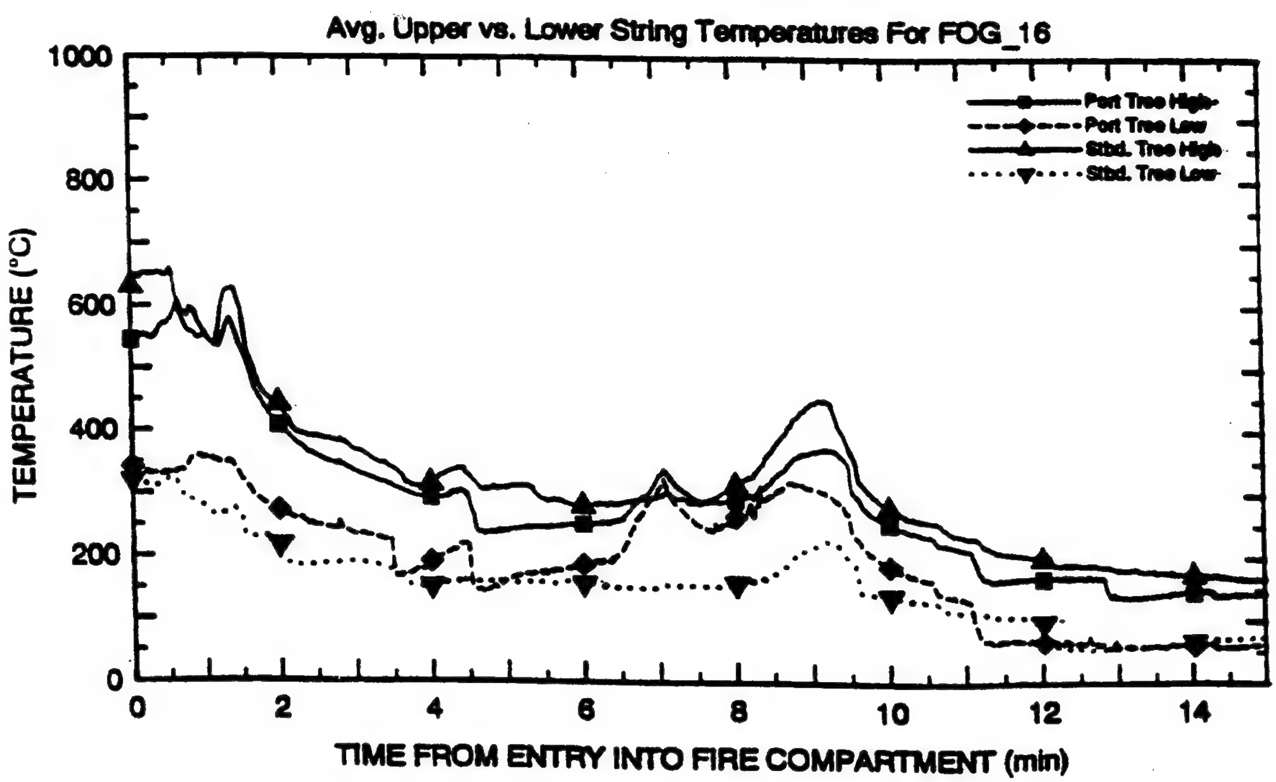


Fig. 21 - Total heat flux and average string temperatures for FOG_16

FOG_17

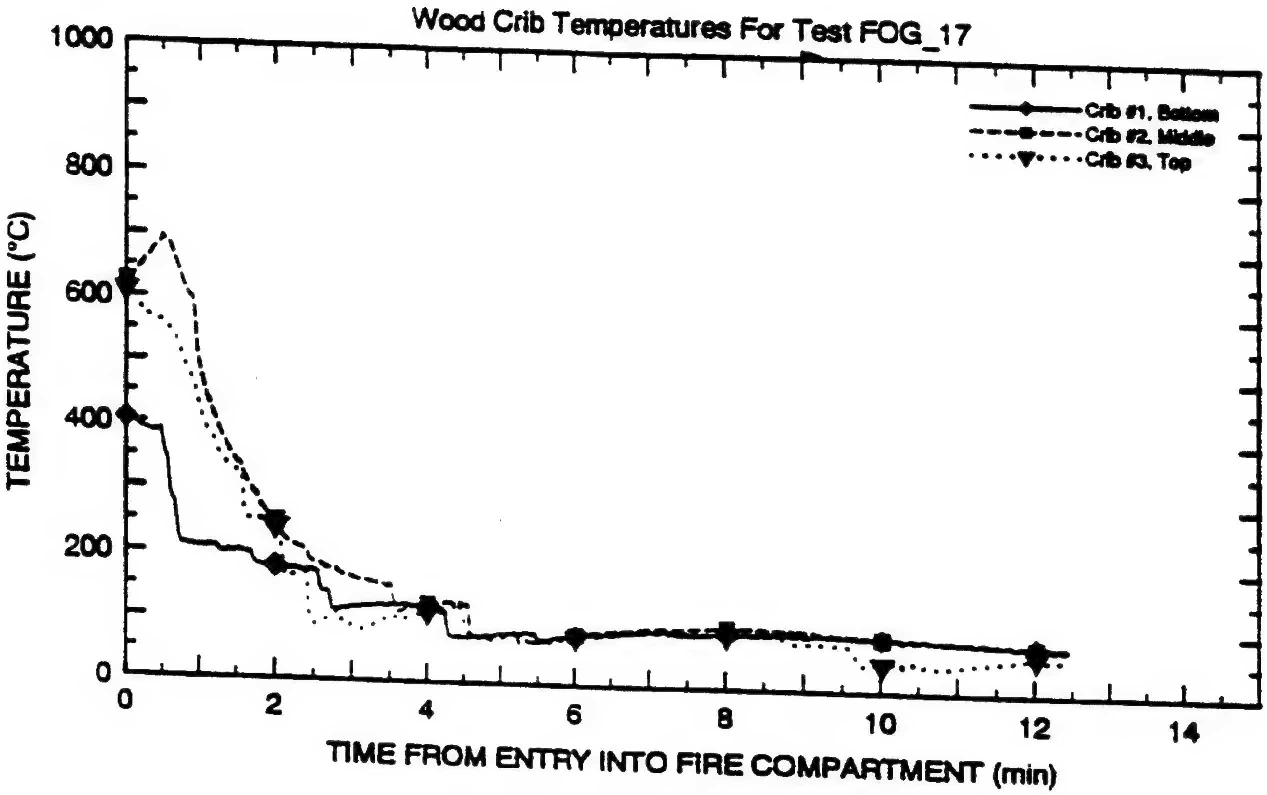
This test was a repeat of FOG_14, except that the offensive fog tactic was used. Entry was made at 13:33 after ignition. Fire conditions at that time were reported to be flames in the overhead above Fire Areas No. 2 and No. 3.

The initial attack consisted of three short bursts with a medium angle fog directed at 45° angle over the locker in front of Fire Area No. 2. The initial burst caused the fire to flare up behind the locker, but this was quickly knocked down by the subsequent bursts. Visibility was also reduced somewhat, but the attack team was still able to advance to attack the seat of the fire directly. After two direct attacks using 3-5s bursts with a straight stream, the nozzleman was relieved. Four more short bursts were directed at the sources of the fires, and the nozzleman was again relieved. At this point, the fire reflashed in Fire Area No. 1. This threat and other hot spots were controlled by the more short bursts before the nozzleman was relieved again.

As the direct attack continued, the fire in Fire Area No. 1 reflashed twice more. A total of nine bursts were required to control this problem. At 19:55 after ignition, the fire was declared out and the safety team relieved the attack team. Table 11 shows the sequence of events for this test while Figs. 22 and 23 present the measures of performance data.

Table 11. - Timeline of Events for FOG_17

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-13:33	Ignition, Fire Party Called Away	0 (0)
	Attack Team Enters Fire Compartment, Reports Flame in Overhead Above Fire Areas #2 and #3 (0:00)	
0:00	Initial Attack With Medium Angle Fog, Aimed Over Fire Area #2, Short Quick Bursts (x3) (0:29)	34 (9)
	Fire Knocked Down, Visibility Also Reduced, Attack Team Advances For Direct Attack (0:39)	
1:00	Direct Attack With Straight Stream, 3-5 s Burst (0:58)	45 (12)
	Direct Attack, 3.5 s Burst (1:14)	61 (16)
	Nozzleman Relieved (1:27)	
	Direct Attack, Short Quick Bursts (x3) (1:33)	98 (26)
2:00	Direct Attack, 3-5 s Burst Off Wall (2:03)	125 (33)
	Nozzleman Relieved (2:07)	
	Reflash in Fire Area #1 (2:12)	
3:00	Direct Attack, Short Quick Bursts (x5), To All Three Fire Areas (2:26)	216 (57)
	Nozzleman Relieved (3:14)	
	Direct Attack to Fire Areas #3 and #1, 3-5 s Bursts (x2) (3:30)	254 (67)
4:00	Fire Reported in Overhead of Fire Area #1 (4:12)	
5:00	Direct Attack to Fire Area #1 Overhead, 3-5 s Burst Followed by Shorter Burst (4:19)	276 (73)
	Direct Attack to Fire Area #1, Short Quick Bursts (x3) (4:33)	303 (80)
6:00	Direct Attack to Fire Area #1 Overhead, 3-5 s Bursts (x2) (5:19)	360 (95)
	Attack Team Exits Compartment, Safety Sets Reflash Watch With 1.9 cm (.75 in) Hoseline (6:22)	
7:00		
	Safety Conducts Overhaul (7:34)	397 (105)
8:00		
9:00		
10:00		
11:00		
12:00		
	Fire Reported Out, Space Vented Using E1-15-2 (12:17)	
13:00		
14:00		



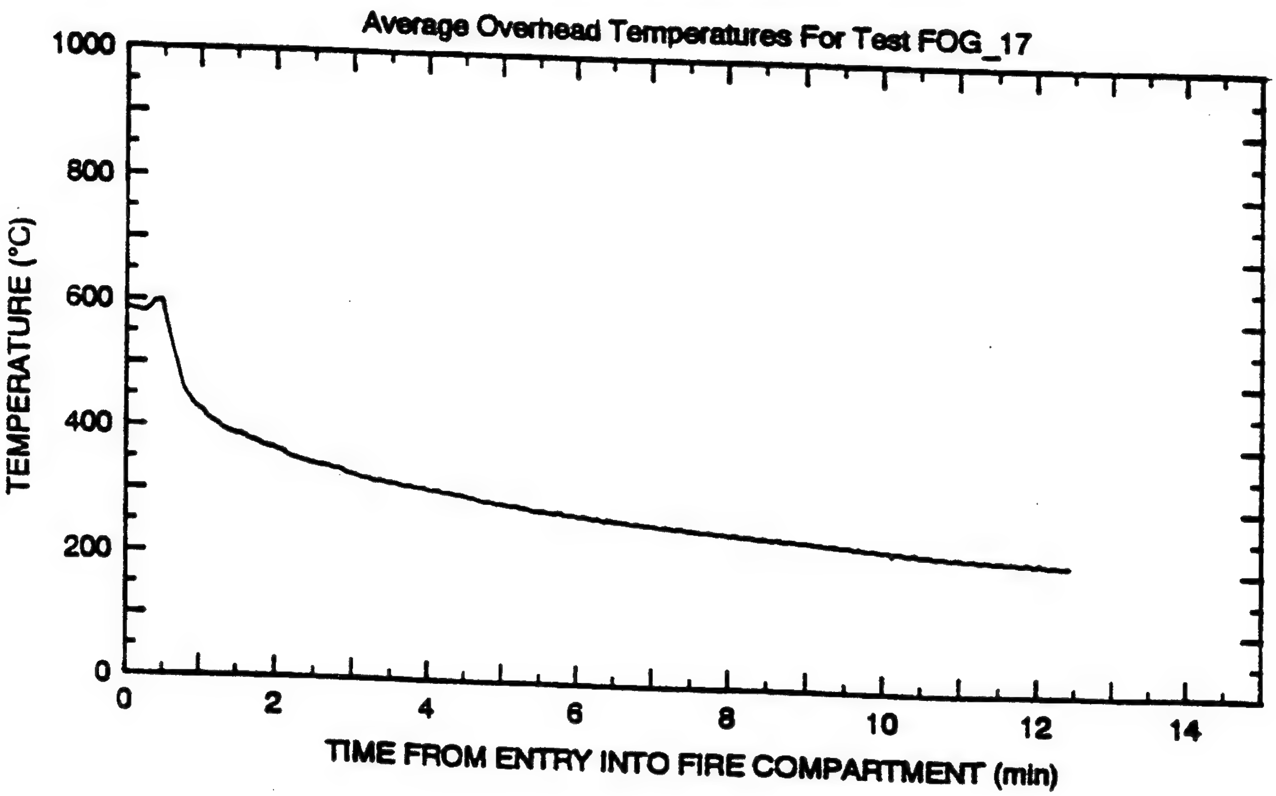


Fig. 22 - Wood crib and average overhead temperatures for FOG_17

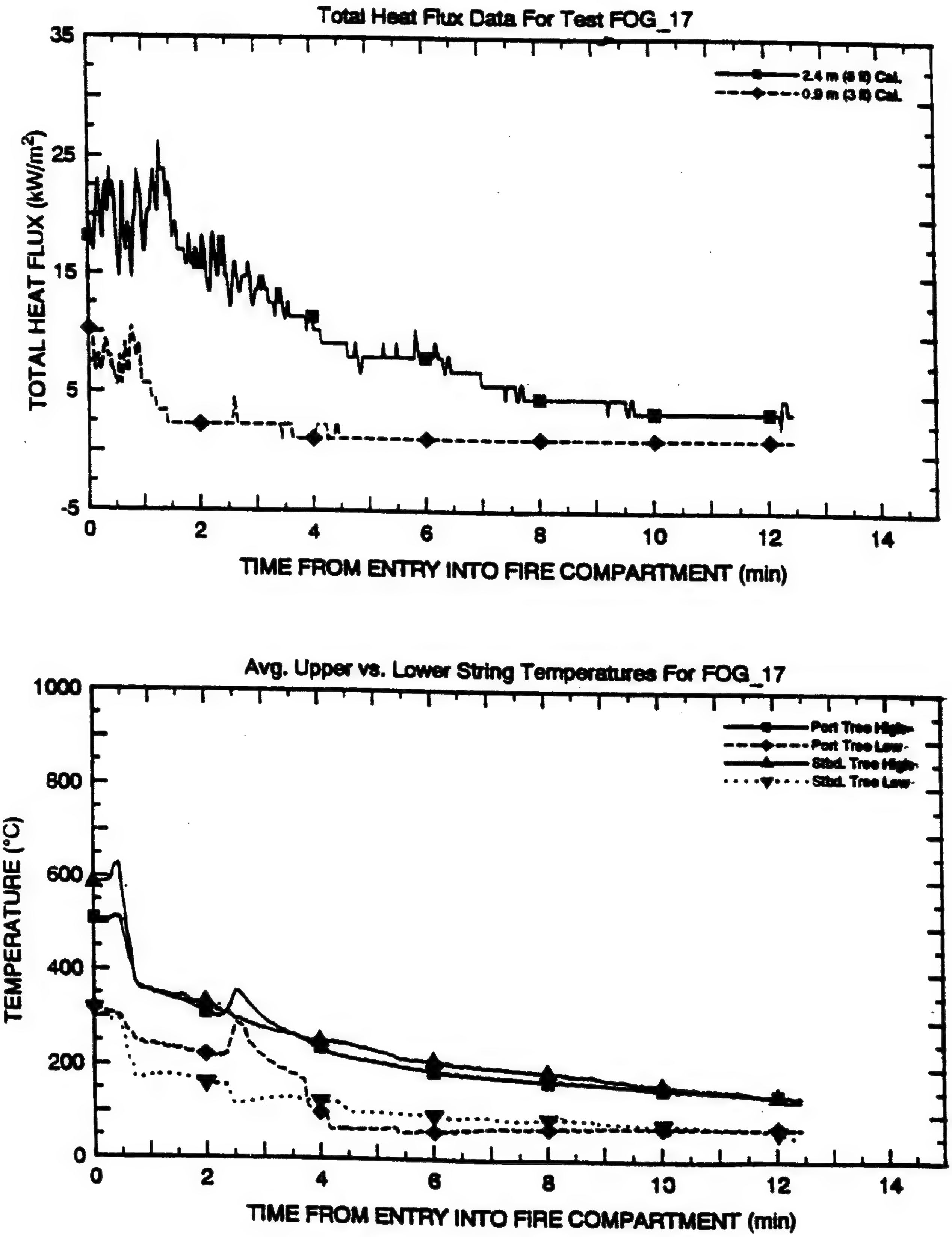


Fig. 23 - Total heat flux and average string temperatures for FOG_17

FOG_18

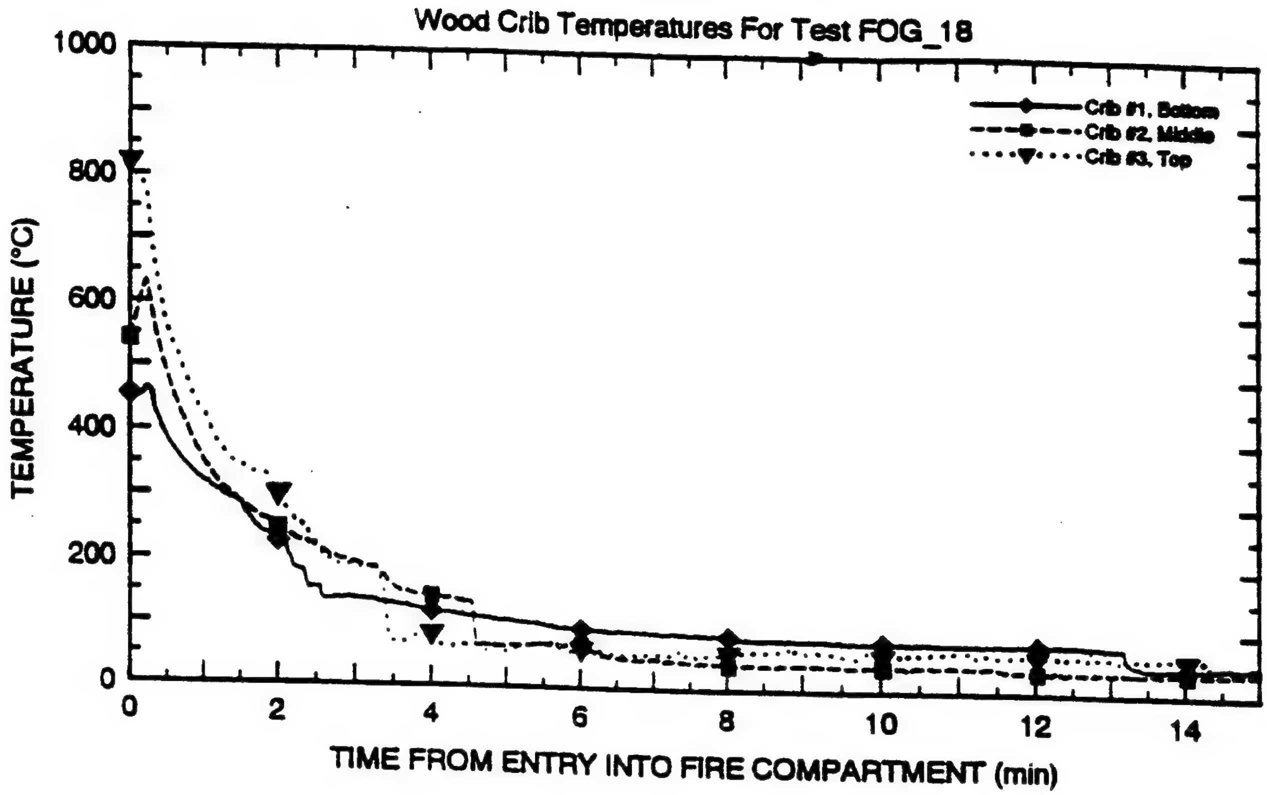
This test was performed using the traditional straight stream tactic. The attack team was comprised of personnel from the Precommissioning Unit of the RUSSEL. Fire Threat No. 1A, which was essentially the same as Fire Threat No. 1 without the obstructions, was used. Entry was made at 12:07 after ignition. Fire conditions at that time were reported to be heavy fire in Fire Areas No. 2 and No. 3 with flames rolling across the overhead.

The initial attack consisted of two short bursts with a narrow angle fog directly on the source of the fire in Areas No. 2 and No. 3. At that point, Fire Area No. 1 flared up and it was immediately knocked down with an additional burst. The attack team reported medium to heavy steam with no visible flames. The nozzleman was then relieved. The attack was continued with four more bursts of straight stream before the nozzleman was again relieved. At this point, the fire reflashed in Fire Area No. 1, but was quickly controlled with two short bursts. Five more quick bursts to the other fire areas suppressed the remaining flames.

The team leader then advanced to the fire areas to investigate for hot spots. A total of sixteen short bursts were needed to complete overhaul. Finally, mop-up was accomplished with a 1.9 cm (0.75-in.) hoseline. The fire was declared out at 21:10 after ignition. Table 12 shows the sequence of events for this test while Figs. 24 and 25 present the measures of performance data.

Table 12. - Timeline of Events for FOG_18

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-12:07	Ignition, Fire Party Called Away	0 (0)
0:00	Attack Team Enters Fire Compartment, Fire Areas #2 and #3 Fully Involved, Fire in Overhead (0:00)	
	Initial Attack, Short Bursts (x2) Directly at Each Body of Fire (Areas #2 and #3) (0:12)	15 (4)
	Fire Area #1 Flares Up, Direct Attack at It, Short Bursts (0:24)	19 (5)
	Attack Team Reports Medium to Heavy Steam, Nozzleman Relieved (0:31)	
	Direct Attack With Straight Stream, Short Bursts (x2) (0:37)	30 (8)
1:00	Attack Team Reports No Visible Flames (0:53)	
	Direct Attack, Short Burst (1:01)	38 (10)
	Direct Attack, Short Burst (1:13)	42 (11)
	Nozzleman Relieved, Fire Area #1 Reflashes (1:23)	
	Direct Attack on Fire Area #1, Short Bursts (x2) (1:31)	49 (13)
2:00	Direct Attack, Short Burst (1:52)	61 (16)
	Direct Attack, Short Quick Bursts (x2) (2:05)	76 (20)
	Direct Attack, 3-5 s Bursts (x2) (2:22)	120 (32)
	Team Leader Investigates With Flashlight, Reports No Visible Flames (2:33)	
3:00	Direct Attack on Hot Spots, Short Bursts (x2) (2:56)	129 (34)
	Direct Attack on Hot Spots, 10-15 s Burst (3:16)	179 (47)
4:00	Indirect Attack Off Bulkhead With Staight Stream, Short Bursts (x2) (3:59)	193 (51)
	Direct Attack, Short Burst (4:16)	207 (54)
	Attack Team Advances to Fire Area #2 (4:23)	
	Direct Attack on Fire Area #3, Short Bursts (x2) (4:33)	220 (58)
5:00	Direct Attack, Short Burst (4:54)	235 (62)
	Team Leader Sets Reflash Watch, Request Relief (5:06)	
	Attack Team Continues Overhaul, Multiple 3-5 s Bursts (x6) (5:23)	326 (86)
6:00		
8:00	3.8 cm (1.5 in) Handline Removed From Compartment, 1.9 cm (.75 in) Hoseline Brought In, Final Mop Up Completed (8:12)	347 (91)
9:00	Fire Declared Out, Space Vented Using E1-15-2 (9:03)	
10:00	Attack Team Leaves Compartment (10:12)	
14:00		



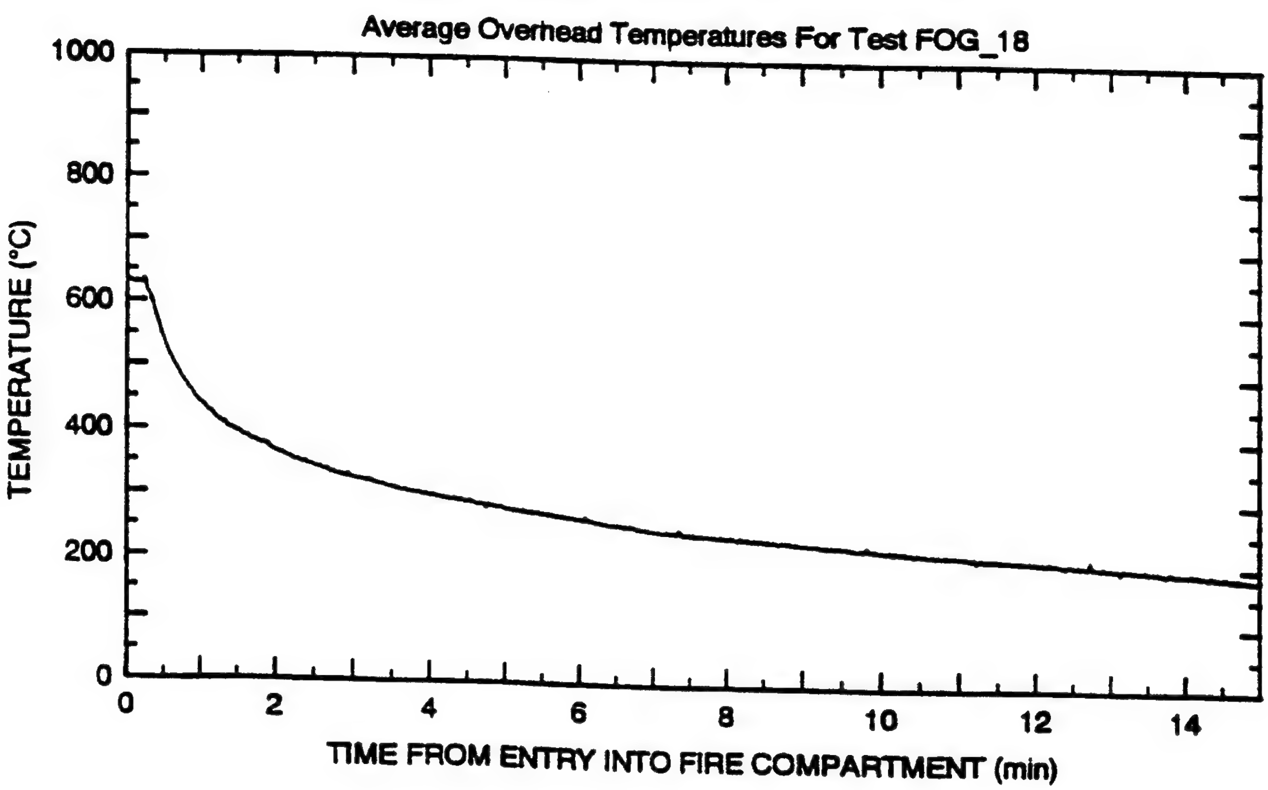


Fig. 24 - Wood crib and average overhead temperatures for FOG_18

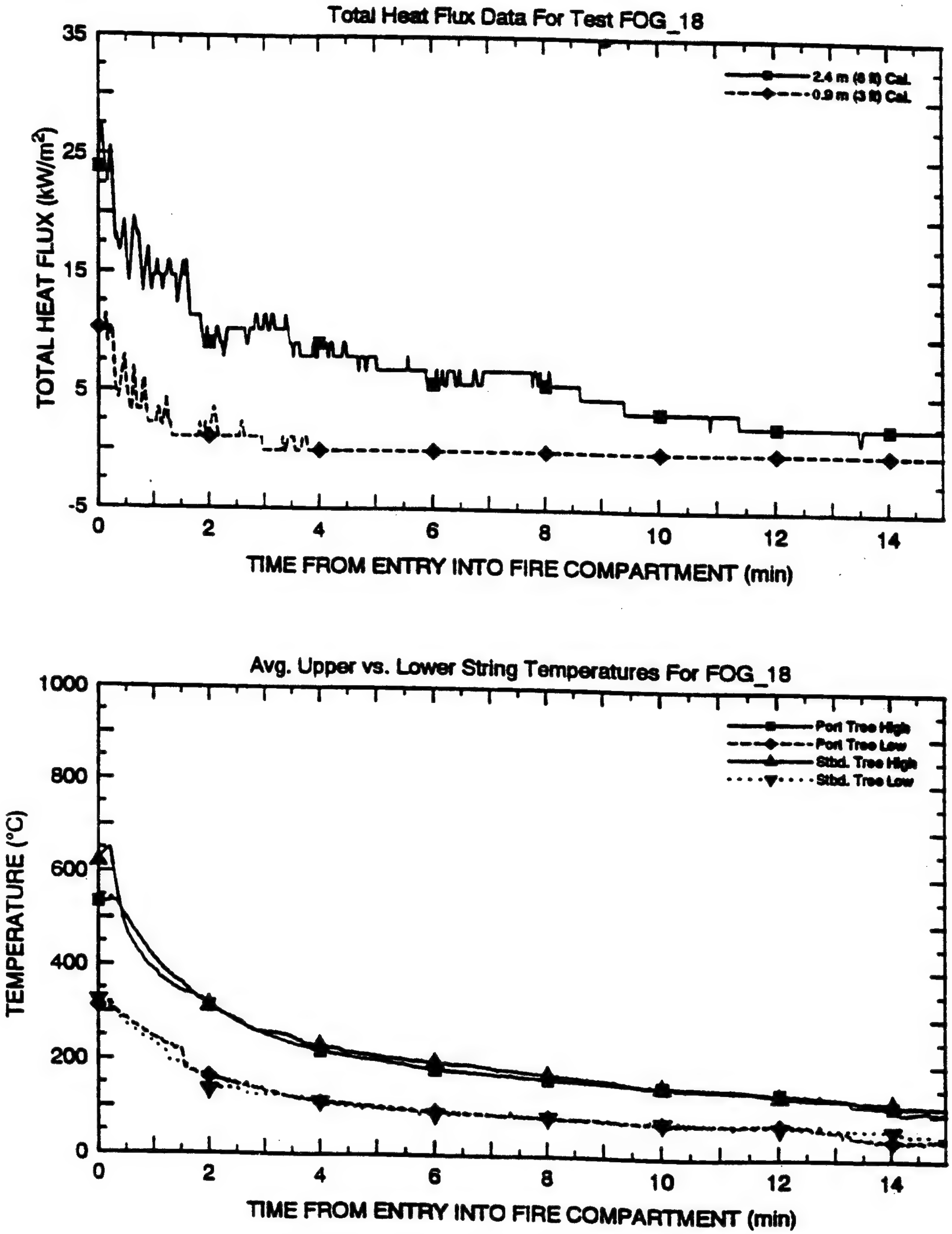


Fig. 25 - Total heat flux and average string temperatures for FOG_18

FOG_19

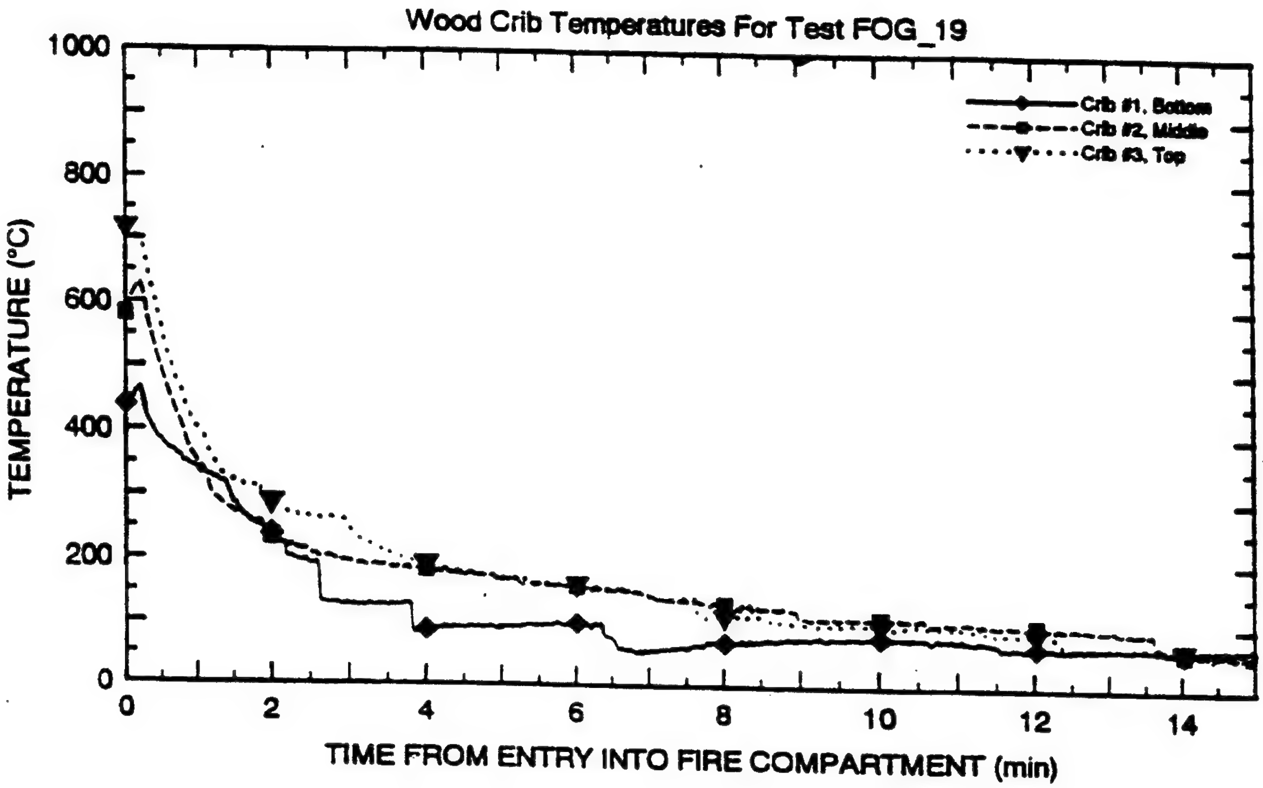
This test was a repeat of FOG_18 except that the offensive fog tactic was used and the attack team consisted of members of the all-female crew. Entry was made at 13:03 after ignition. At that time the compartment was reported to be well involved with flames in the overhead.

The initial attack consisted of three quick bursts with a medium angle fog directed at 45° angle at the fire in the overhead. This resulted in steam banking down and visibility being reduced. The team leader reported no visible flames, and the nozzleman was relieved due to steam/heat stress. Three more fog attacks only had the effect of increasing the steam insult. Despite the steam conditions, the attack team was able to position for their direct attack. The direct attack consisted of four bursts with a straight stream directly at the seat of the fires. With no visible flames, the attack team backed out to the doorway, looking for hot spots with a flashlight.

A total of six bursts of straight stream were directed from the doorway before the nozzleman had to be relieved again. After one more burst, the 3.8 cm (1.5-in.) hoseline was replaced with a 1.9 cm (0.75-in.) hoseline for overhaul. Only one hot spot was found and the fire was declared out at 18:53 after ignition. Table 13 shows the sequence of events for this test while Figs. 26 and 27 present the measures of performance data.

Table 13. - Timeline of Events for FOG_19

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-13:03	Ignition, Fire Party Called Away	
	Attack Team Enters Fire Compartment, Reports Fire Well Involved, Flames in Overhead (0:00)	0 (0)
0:00	Initial Attack With Medium Angle Fog, Three Quick Bursts Over 3-5 s Period, Steam Banked Down (0:12)	11 (3)
	Attack Team Reports No Visible Flames, Nozzleman Relieved (0:17)	
	Fog Attack, Single 3-5 s Burst, More Steam (0:27)	26 (7)
	Fog Attack, Extended 15-20 s Burst, Still More Steam (0:37)	64 (17)
1:00	Fog Attack, 5-10 s Burst Followed Immediately by 3-5 s of Throttled Flow, Steam Still Heavy (1:02)	83 (22)
	Attack Team Positions For Direct Attack (1:17)	
	Direct Attack With Straight Stream, 3-5 s Burst (1:25)	95 (25)
	Attack Team Reports No Visible Flames (1:36)	
	Direct Attack at Fire Area #1, Short Burst (2:01)	102 (27)
2:00	Direct Attack at Fire Area #3, 3-5 s Bursts (x2) (2:09)	125 (33)
	Attack Team Backs Out to Doorway, Uses Flashlight to Look for Fire or Hot Spots (2:17)	
	Direct Attack From Doorway, Short Burst (2:31)	132 (35)
3:00	Direct Attack From Doorway, Short Bursts (x4) (2:53)	163 (43)
	Direct Attack, Short Burst (3:17)	167 (44)
	Nozzleman Relieved (3:36)	
	Direct Attack, Short Burst (3:51)	170 (45)
4:00		
	3.8 cm (1.5 in) Hoseline Backed Out of Compartment Replaced by 1.9 cm (.75 in) Hoseline (4:15)	
	Overhaul in Fire Area #1, Short Burst (4:34)	170 (45)
5:00		
	Fire Declared Out, Attack Team Continues Overhaul and Compartment Cooling (5:50)	229 (61)
6:00		
9:00		
	Attack Team Exits Fire Compartment, Test Concluded, Space Ventilated Using E1-15-2 (9:41)	
10:00		
13:00		
14:00		



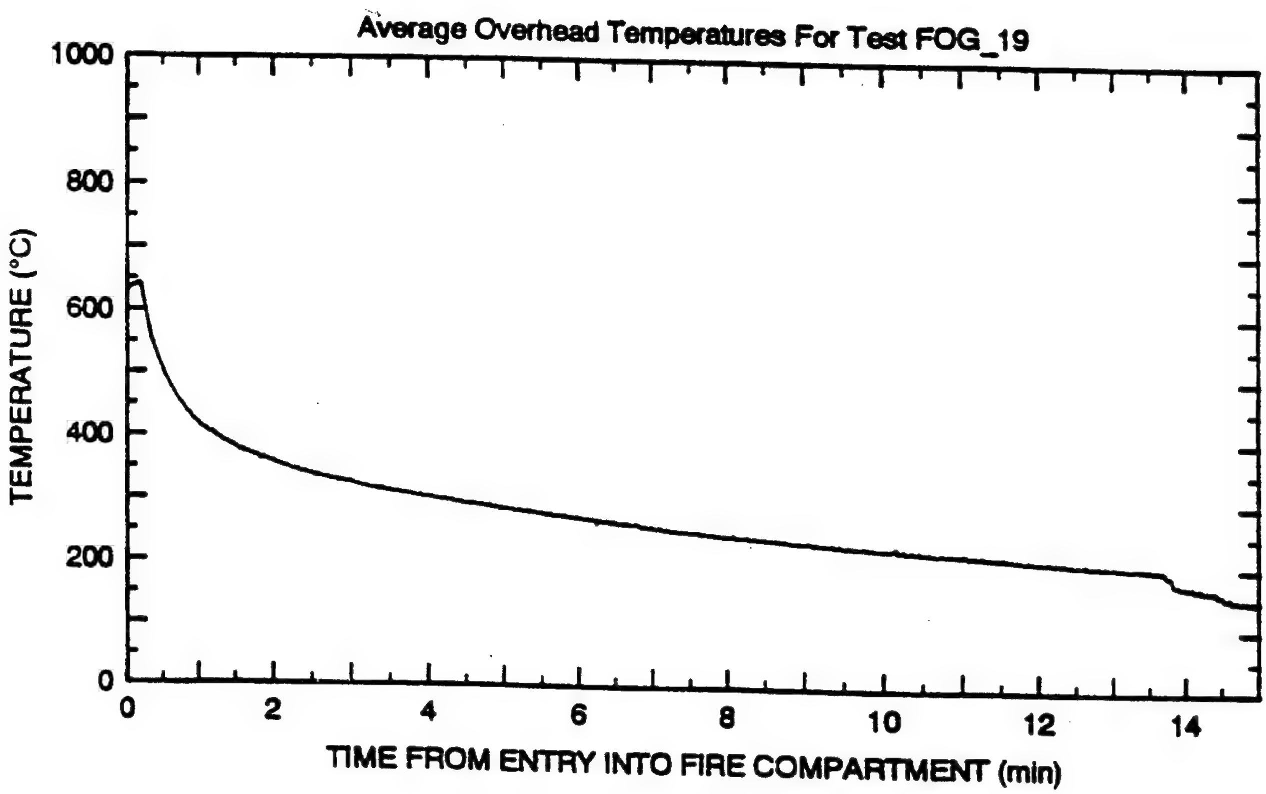
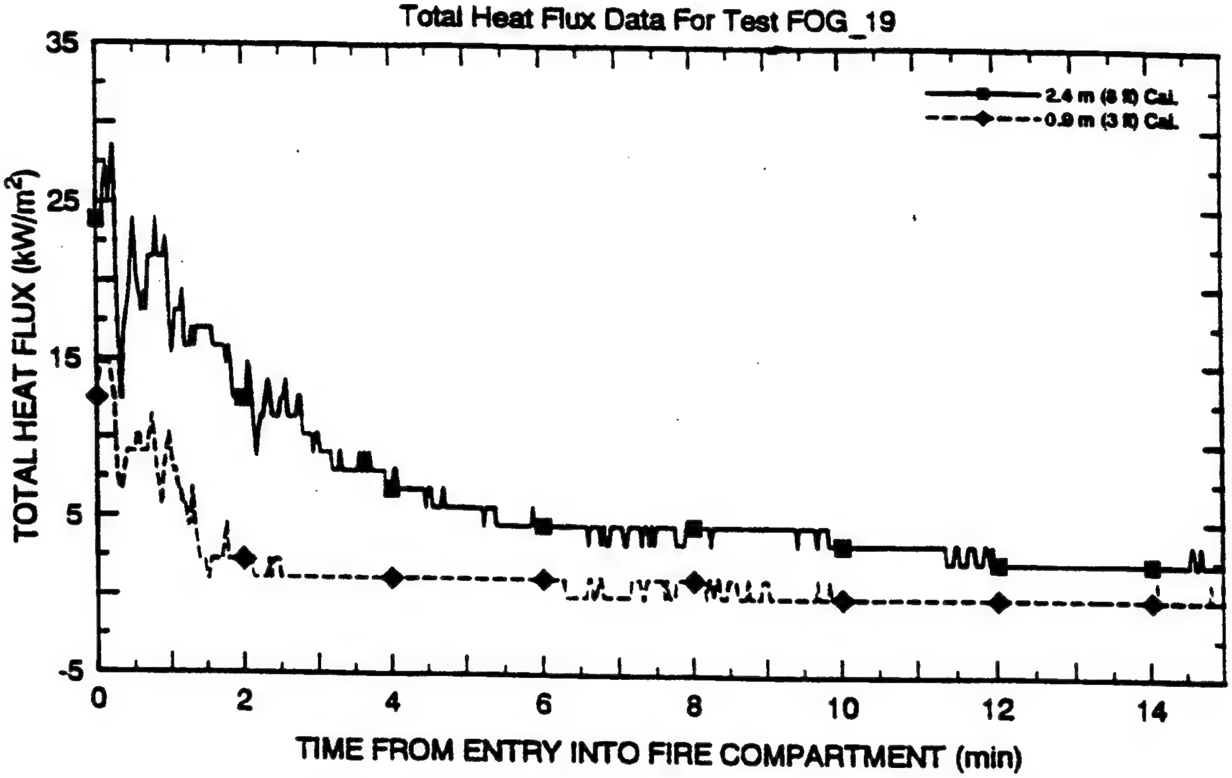


Fig. 26 - Wood crib and average overhead temperatures for FOG_19



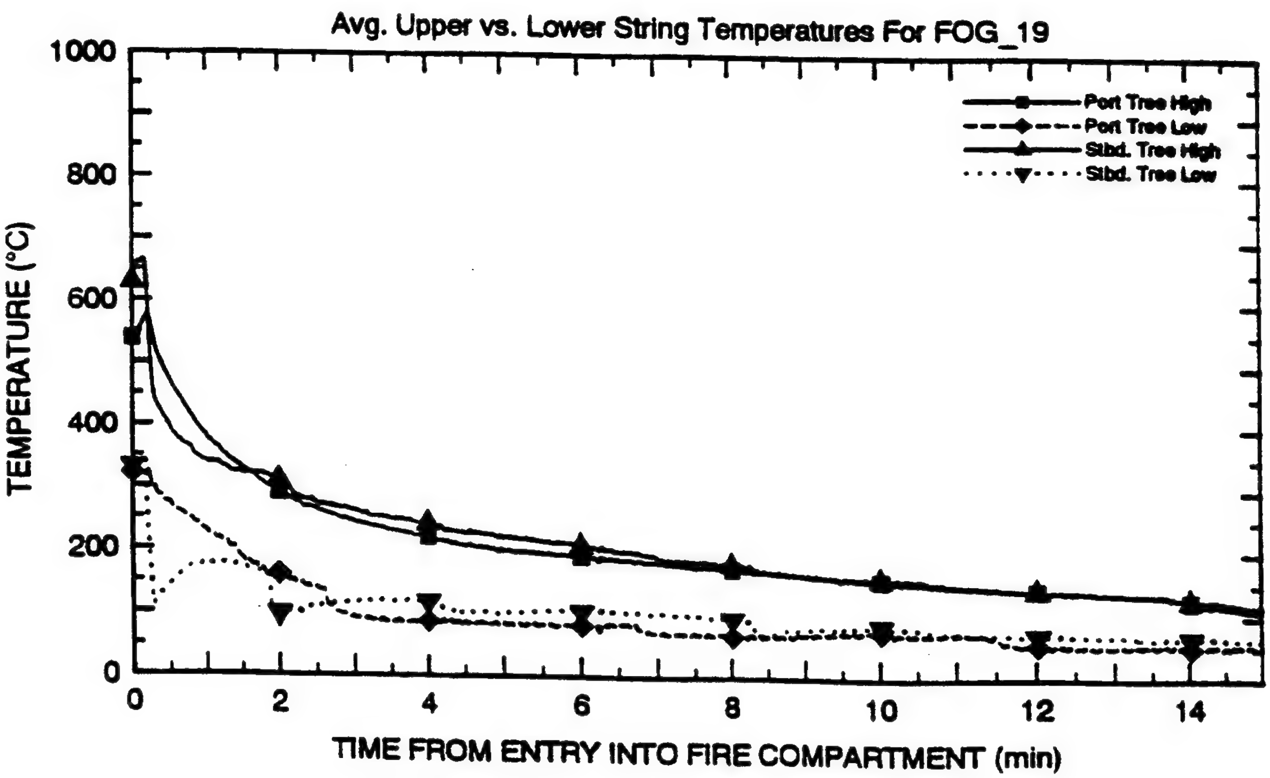


Fig. 27 - Total heat flux and average string temperatures for FOG_19

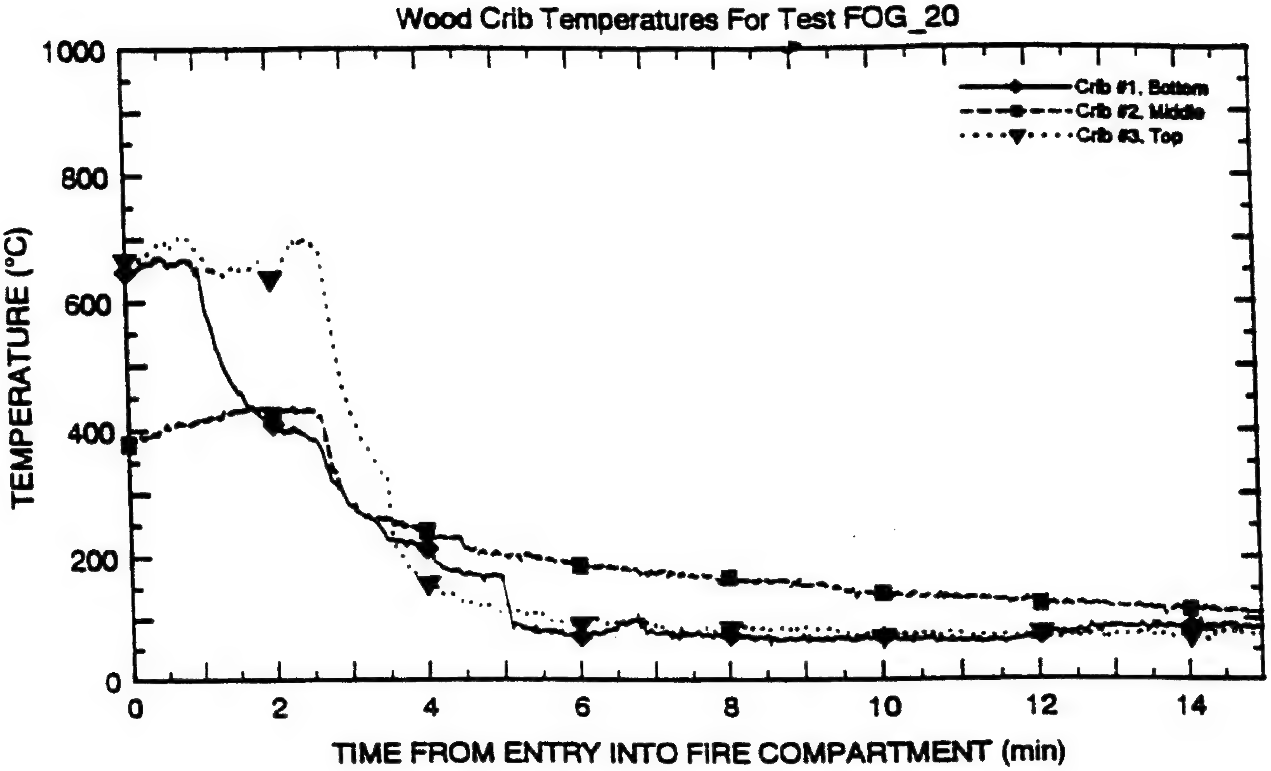
FOG_20

This test was the "low visibility" scenario using Fire Threat No. 2. The attack team was comprised of personnel from the PEB crew. At 12:51, the attack team entered the starboard passageway, where visibility was still good despite light smoke. At 14:32, the attack team entered GSK, where visibility was poor and the heat conditions were more noticeable. The team leader decided that the NFTI was needed in this compartment. At 16:21, the attack team entered the fire compartment. The team leader reported no visible flames, but he could hear the fire crackling. The NFTI was abandoned because of white-out from the intense heat.

The initial attack consisted of three short bursts with a medium angle fog at a 45° angle from just inside the doorway. With conditions still tenable, the attack team advanced 0.6-0.9 m (2-3 ft) further in and began direct attacks with a straight stream. After ten bursts, the team advanced still further in. After two more bursts, the team leader had to be relieved. The direct attack continued with five more bursts. As the attack team continued to advance, they reported that the compartment was noticeably cooler. After three more bursts the attack team was able to begin overhaul. Overhaul was eventually completed with the 1.9 cm (.75-in.) hoseline and at 27:06 after ignition, the fire was declared out. Table 14 shows the sequence of events for this test while Figs. 28 and 29 present the measures of performance data.

Table 14. - Timeline of Events for FOG_20

Time From Attack Team Entry (min:sec)	Event (Time From Attack Team Entry, min:sec)	Cummulative Total of Water Used L (gal)
-12:51	Ignition, Fire Party Called Away	0 (0)
	Attack Team Enters Starboard Passageway, Reports Some Smoke, Visibility Not Too Bad (-1:41)	
0:00	Attack Team Enters GSK, Reports Poor Visibility, Heat Not Too Bad, Using NFTI (0:00)	
	Team Leader Approaches Fire Compartment Doorway, Can Hear Fire But Not See it (0:54)	
1:00		
	Attack Team Enters Fire Compartment, Reports No Visible Flames, NFTI Abandoned Due to White-Out (1:42)	
2:00		
	Initial Attack With Medium Angle Fog, Short Quick Bursts (x3), From Just Inside Doorway (2:36)	34 (9)
3:00		
	Attack Team Advances 0.6-0.9m (2-3 ft) Into Compartment (3:08)	
	Direct Attack With Straight Stream, Short Bursts (x3) a 5-10 s Intervals (3:31)	61 (16)
4:00		
	Direct Attack With Straight Stream, Short Burst (4:08)	68 (18)
	Direct Attack, Short Bursts (x2) (4:25)	79 (21)
	Direct Attack, Short Burst (4:36)	91 (27)
5:00		
	Direct Attack, Short Bursts (x2) (4:59)	106 (28)
	Direct Attack, Short Burst (5:34)	117 (31)
	Attack Team Advances Further Into Compartment (5:43)	
6:00		
	Direct Attack, Short Bursts (x2) (5:54)	136 (36)
	Team Leader Relieved (6:15)	
	Direct Attack, Short Quick Bursts (x3) (6:43)	151 (40)
7:00		
	Direct Attack, Short Bursts (x2) (7:11)	163 (43)
	Attack Team Advances Further Into Compartment, Reports Compartment is Noticeably Cooler (7:18)	
	Direct Attack, Short Burst (7:26)	170 (45)
8:00		
	Direct Attack, 3-5 s Burst (7:48)	182 (48)
	Direct Attack, 3-5 s Burst (8:01)	189 (50)
	Attack Team Begins Overhaul Process (8:28)	
9:00		
	Direct Attack, 3-5 s Burst (8:44)	197 (52)
	Direct Attack, Short Burst (8:58)	201 (53)
	Indirect Attack Off Bulkhead, 10-15 s Throttled Burst, Steam Generated (9:10)	212 (56)
10:00		
	Direct Attack, Short Bursts (x2) (9:28)	220 (58)
	Overhaul Completed Using 1.9 cm (.75 in) Hoseline (10:38)	223 (59)
11:00		
12:00		
	Fire Reported Out, Attack Team Exits Compartment, Space Vented Using E1-15-1 (12:34)	
13:00		
14:00		
15:00		



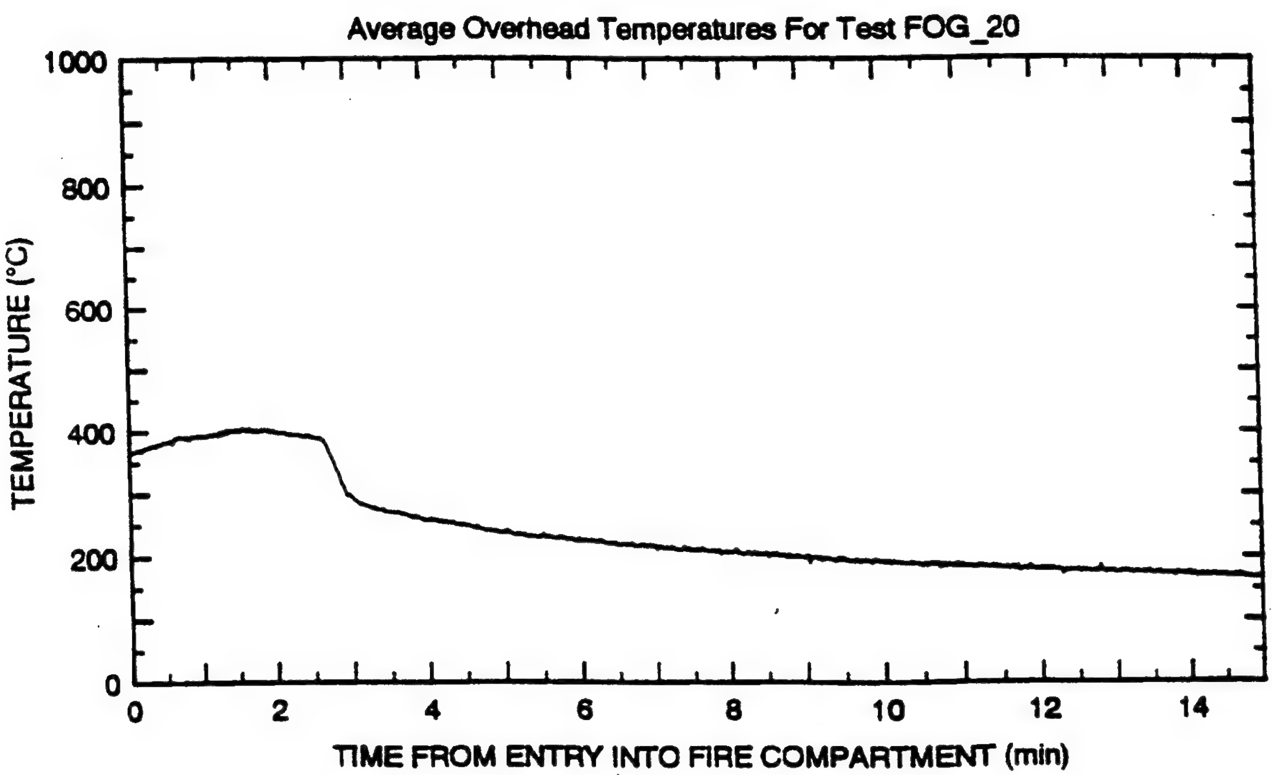
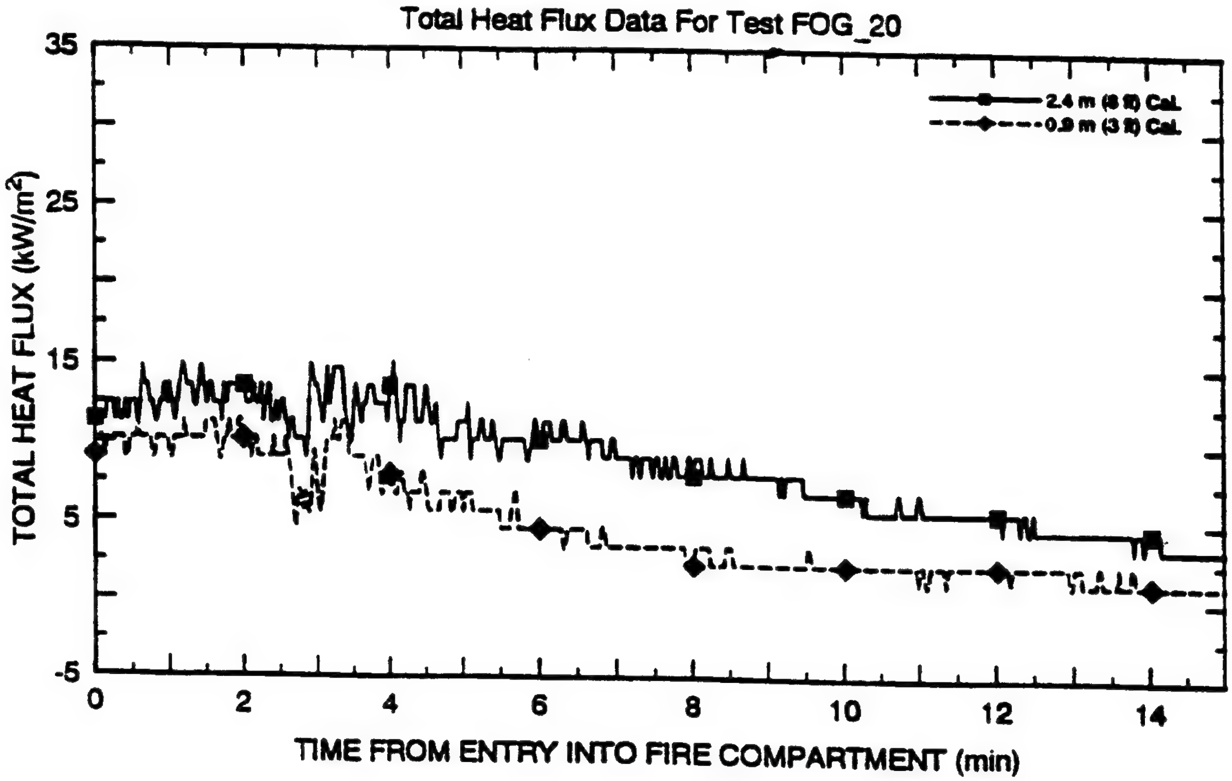


Fig. 28 - Wood crib and average overhead temperatures for FOG_20



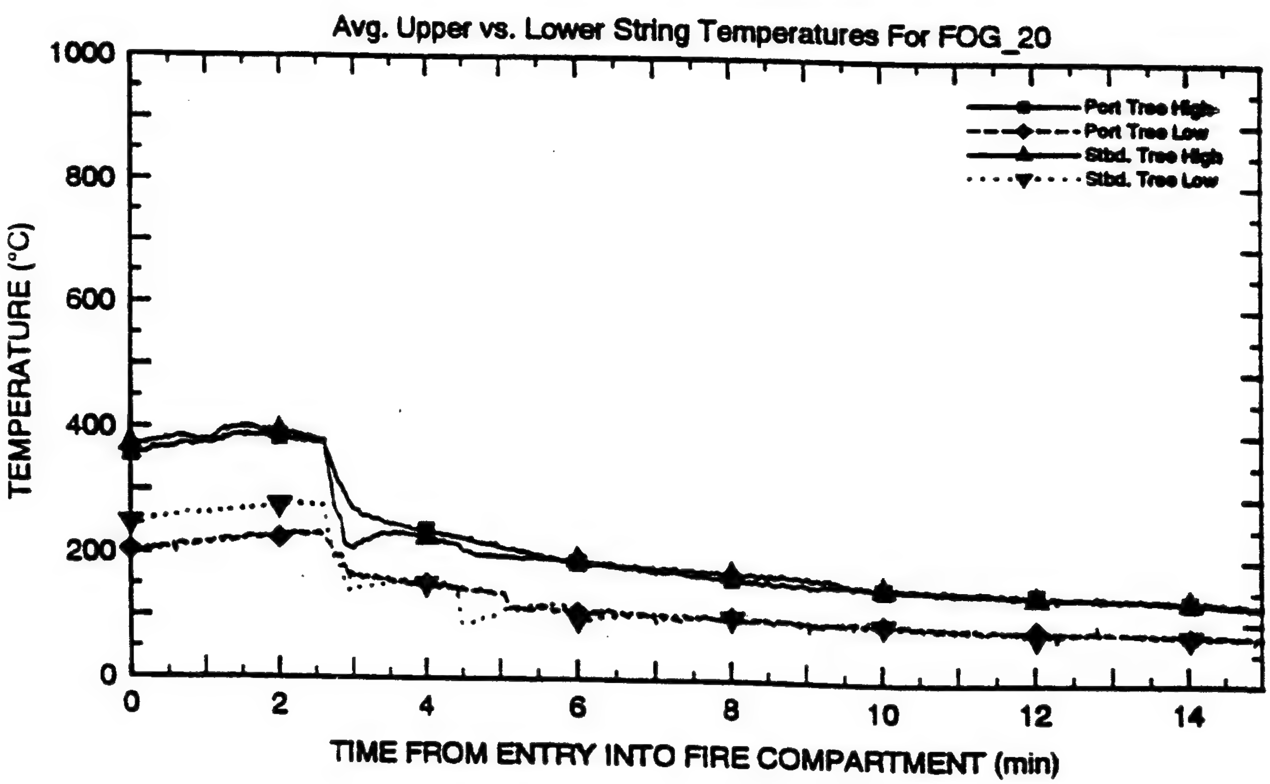


Fig. 29 - Total heat flux and average string temperatures for FOG_20

Specific Findings

The following specific findings were developed based on comments and discussions presented during the debriefings.

Tactics and Procedures

(1) In general, the growing/steady state fire (FOG_12 - FOG_19) provided a challenging thermal threat, but conditions (visibility and heat threat) were such that a direct attack as defined in NSTM 555 could be attempted.

(2) Lack of knowledge of the compartment layout and the need to determine how to best get around the obstruction slowed down the attack sufficiently that controlling the overhead fire became a primary requirements.

(3) The offensive fog attack using a medium angle fog stream directed at a 45° angle up into the flaming overhead resulted in the least amount of disturbance to the thermal layer. While steam was produced, it was described as more of a moist, "sweaty" type of steam rather than a hot, penetrating steam.

(4) The traditional straight stream attacks conducted in accordance with NSTM 555 typically resulted in large amounts of steam being generated. This was attributed to the fact that the hose streams had to be deflected off hot bulkheads and the overhead to get water on to the seat of the fire.

(5) In situations where the attack teams had to back out of the space, it was generally because of the steam threat rather than the heat threat.

(6) The offensive fog attacks resulted in no burns to the participants while the traditional straight stream attacks resulted in burns to the hands, wrists, face, neck, and back.

(7) Water management is important when controlling the overhead fire, particularly when using a straight stream or narrow angle fog. Excess water will only result in excess steam. Water flow should be controlled by using short bursts and opening the nozzle only as much as needed.

(8) The reflashes that continually occurred proved to be a significant disruption and source of frustration. In general, this prevented the attack teams from getting control of the overall situation. This indicates a need to handle each fire source individually, completely controlling it before moving on to the next, while maintaining control of the overhead at the same time.

(9) Relief of the nozzleman is important, particularly during extended firefighting efforts such as these. This was best accomplished by rotating team members on the hoseline. This rotation should occur before individuals are completely worn-out or over-stressed.

Equipment

(1) Flash gloves in combination with the standard firefighting gloves were needed to provide an adequate level of protection, particularly to the hands and wrists.

(2) Most of the wrist burns occurred on arms that were extended outward from the body (i.e., pointing at something or operating a nozzle). This indicates a need for longer wrist protection on either the gloves or FFEs.

(3) Burns to the back of hands occurred mostly when the gloves were tight against the hand, indicating a need for gloves that are large enough to maintain the air gap.

(4) The NFTI proved to be ineffective during the initial stages of attack due to white-out. It was typically abandoned at that point.

(5) The attack teams indicated that the 1.9 cm (0.75-in.) hoseline was preferred for mop-up and overhaul operations.

Training

(1) The consensus was that the heat and steam threat experienced at the fire schools is not nearly as great as in these more realistic scenarios. Also the training fires tend to go out much quicker and with less water. The lack of steel in the trainers reduced the production of steam.

(2) Communications between hose team members and the team leader is a basic skill that is very important. Lack of communications slowed the attack teams progress and made it more difficult to get relief for the nozzleman. There was one instance where the team leader had left the space without the attack team knowing it. The result was a lack of direction causing the attack team to back out and regroup.

DISCUSSION

Firefighting Tactics

Based on both the quantitative and qualitative results of these tests, the use of a medium angle fog stream aimed 45° upward at the flaming overhead and discharged in short bursts appears to be an effective tactic for controlling an overhead fire threat. The rationale in NSTM 555[2] for avoiding this tactic is the concern of generating excess steam, disturbing the thermal balance, and reducing visibility and comfort within the fire compartment. The data from these tests indicate that for this fire threat, the offensive fog attack method can be used to control the overhead fire without disturbing the thermal balance. The steam that was generated may contribute to fire extinguishment, although this cannot be absolutely

quantified by the data. The overall effectiveness of the technique was evident by the success of the teams using the offensive fog tactic as supported by the measures of performance and qualitative feedback from the participants.

Control of the overhead fire threat is best shown by the average overhead temperature data. Figures 30-32 present this data for both the traditional straight stream and the offensive fog attack evolutions of the RUSSEL, the all female, and the PEB teams, respectively. The data for the RUSSEL and PEB teams show that with the offensive fog tactic (FOG__15 and FOG__17), the overhead temperatures were immediately reduced by 200-250°C (392-482°F) and then continued to cool for the duration of the evolution. The graph for the all female team (FOG__13) showed similar trends, except that the initial temperature drop occurred more slowly and there were two instances where the temperature rebounded due to reorganization of the hose team. Comments from the female attack team indicate that the reasons for these rebounds were not related to the attack method, but rather were a function of training, familiarity with other team members, and lack of aggressiveness.

In contrast, the data for the traditional straight stream tactic (FOG__12, FOG__14, and FOG__16) show that the overhead temperatures were reduced initially but quickly rebounded back to their original values. With each subsequent attempt to control the overhead fire, the same results were observed. This validates the attack team observations that they were never really able to get control of the fire during the traditional/straight stream evolutions.

Disturbances of the thermal balance within the fire compartment are best shown by comparing the total heat flux data measured by the calorimeters mounted 0.9 m and 2.4 m (3 ft and 8 ft) above the deck in the fire compartment. Figures 33-35 present a side by side comparison of this data for the traditional straight stream and offensive fog attack evolutions of the RUSSEL, the all female, and the PEB teams respectively. The key indicator of significant disturbances in the thermal balance is an upward spike in the

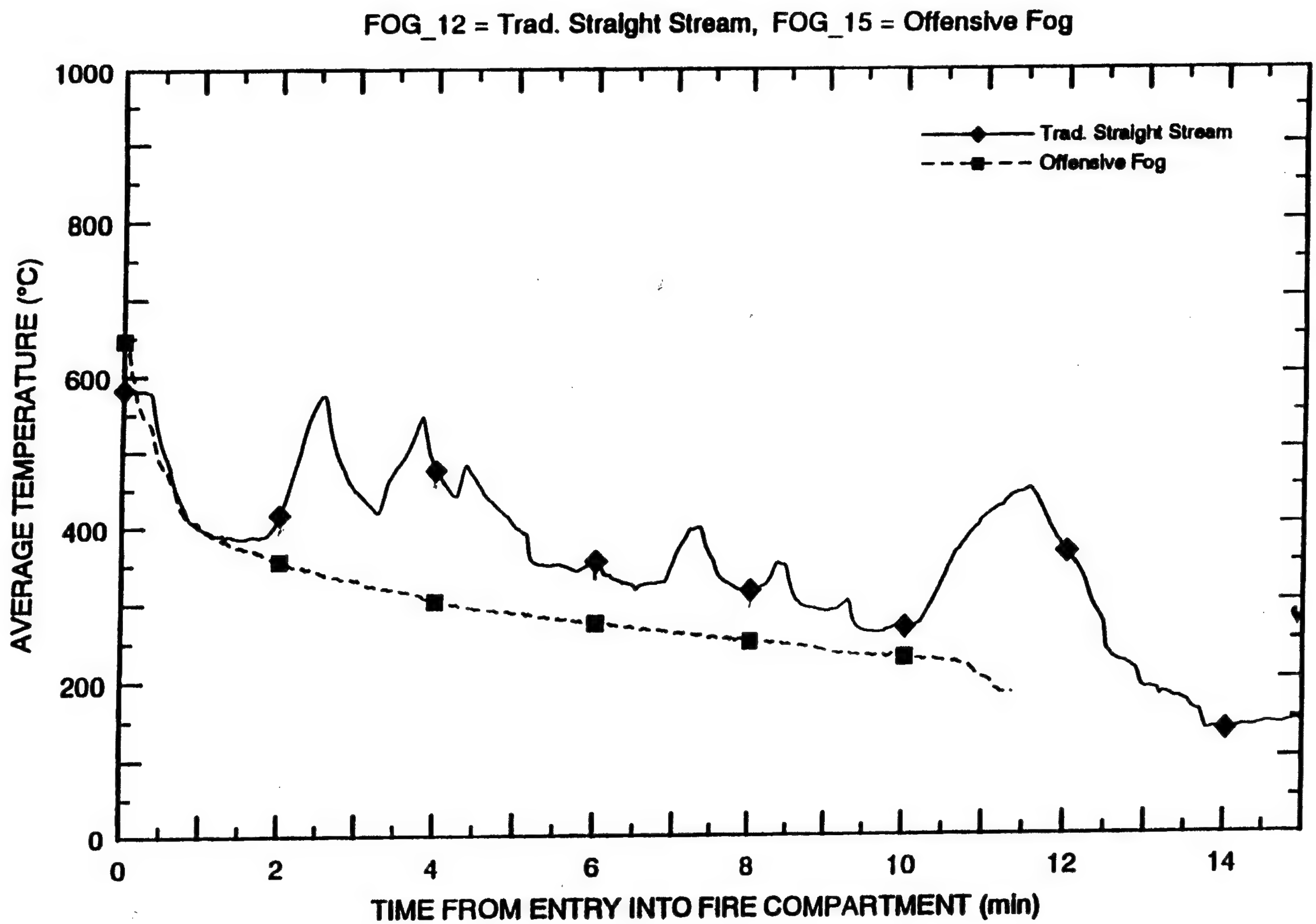


Fig. 30 - Comparison of average overhead temperatures for FOG_12 and FOG_15 (USS RUSSEL team)

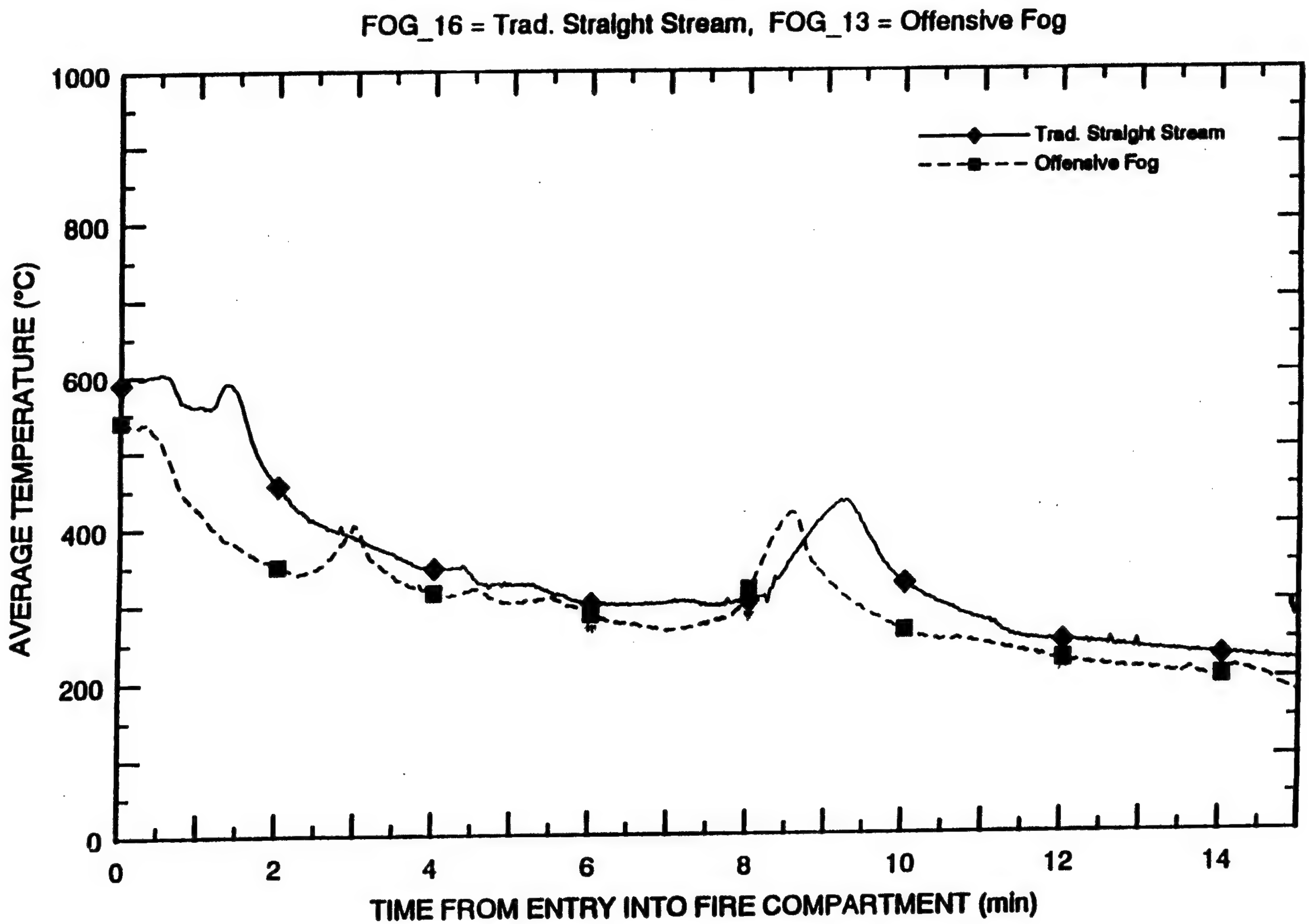


Fig. 31 - Comparison of average overhead temperatures for FOG_16 and FOG_13 (Female team)

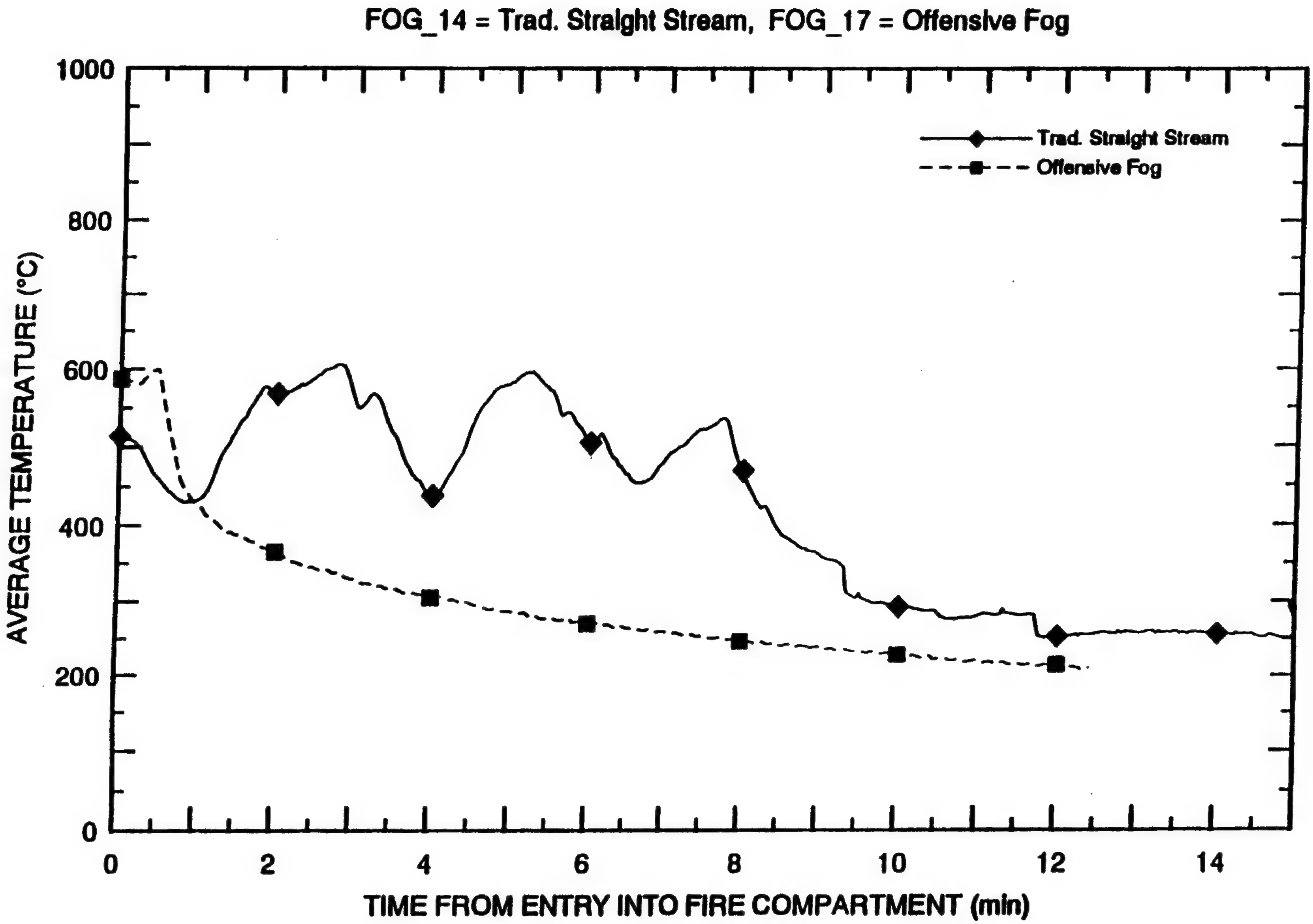
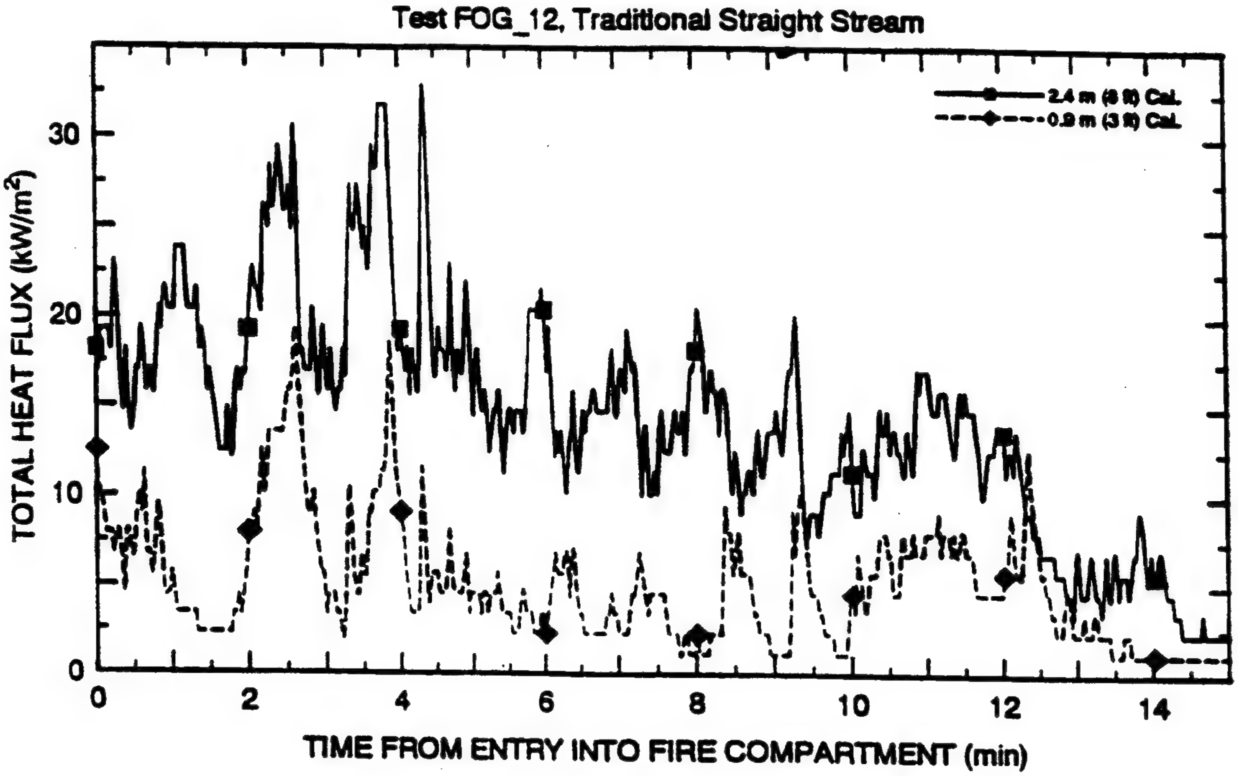


Fig. 32 - Comparison of average overhead temperatures for FOG_14 and FOG_17 (PEB team)



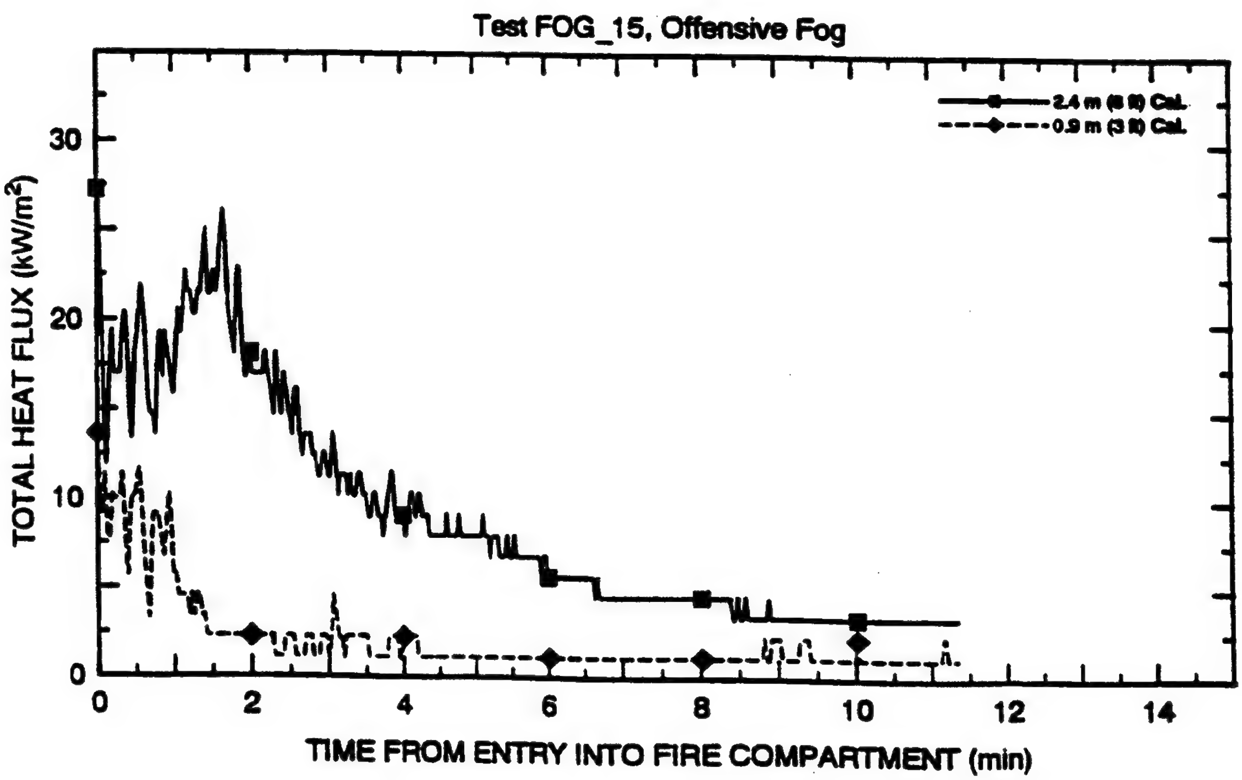
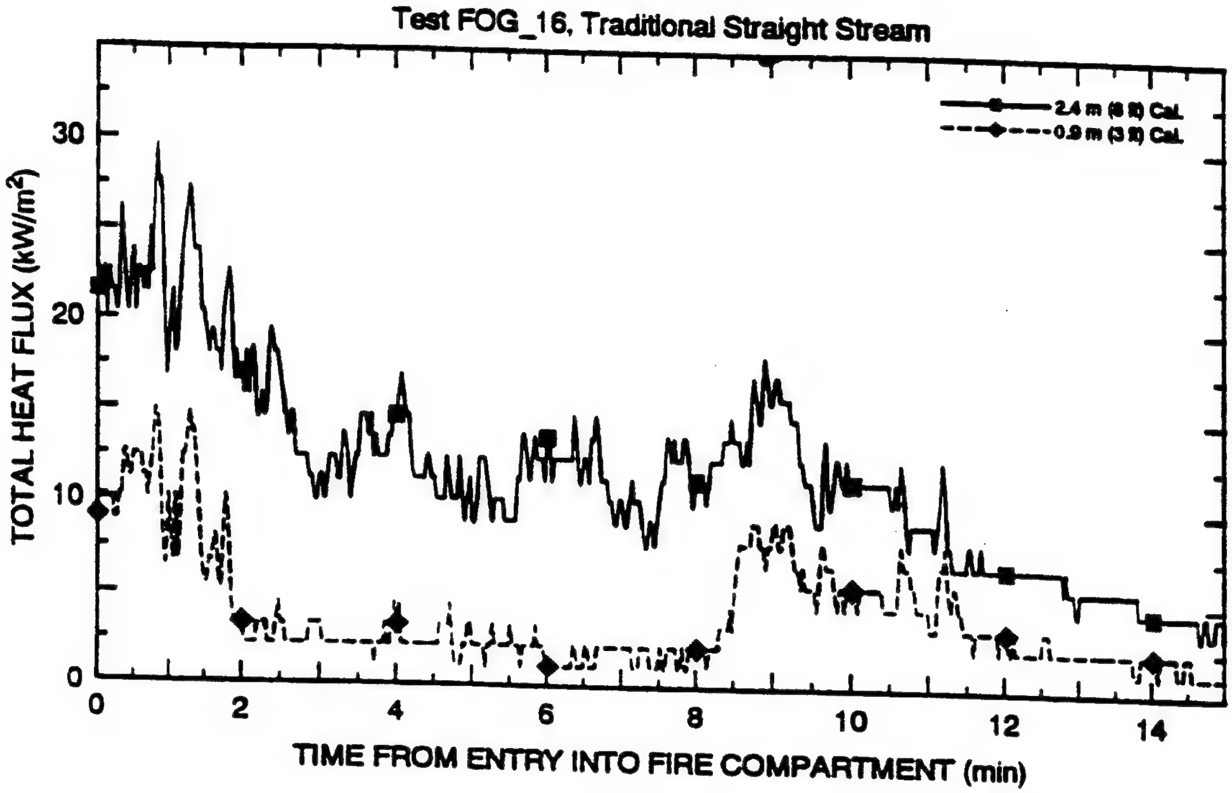


Fig. 33 - Total Heat Flux Data for FOG_12 and FOG_15 (USS RUSSEL team)



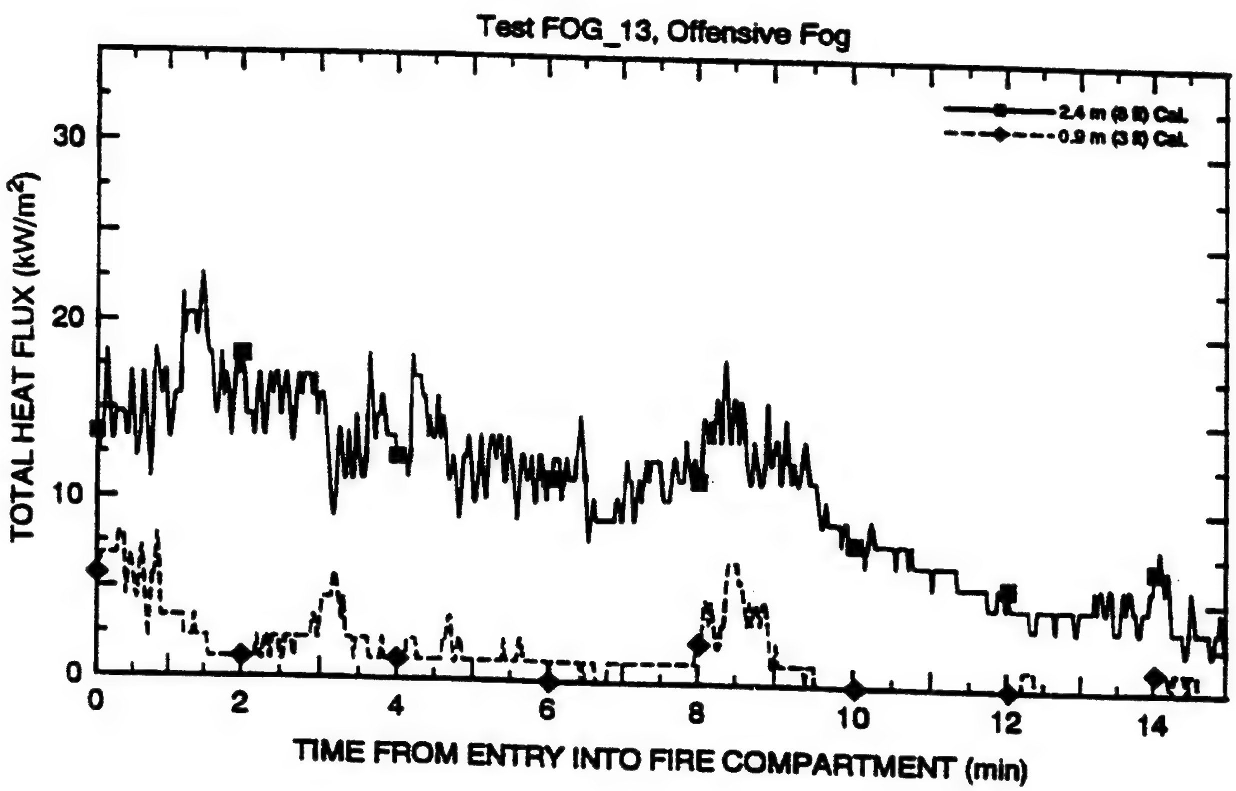
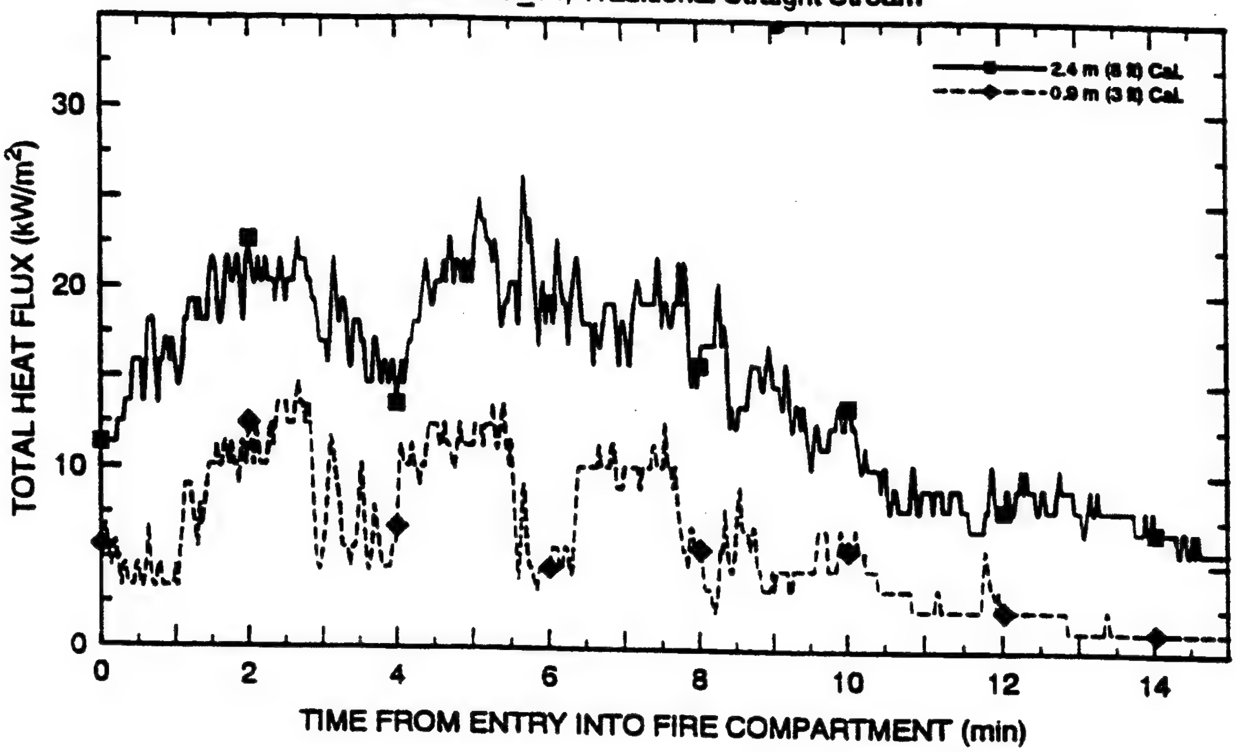


Fig. 34 - Total Heat Flux Data for FOG_16 and FOG_13 (Female team)

Test FOG_14, Traditional Straight Stream



Test FOG_17, Offensive Fog

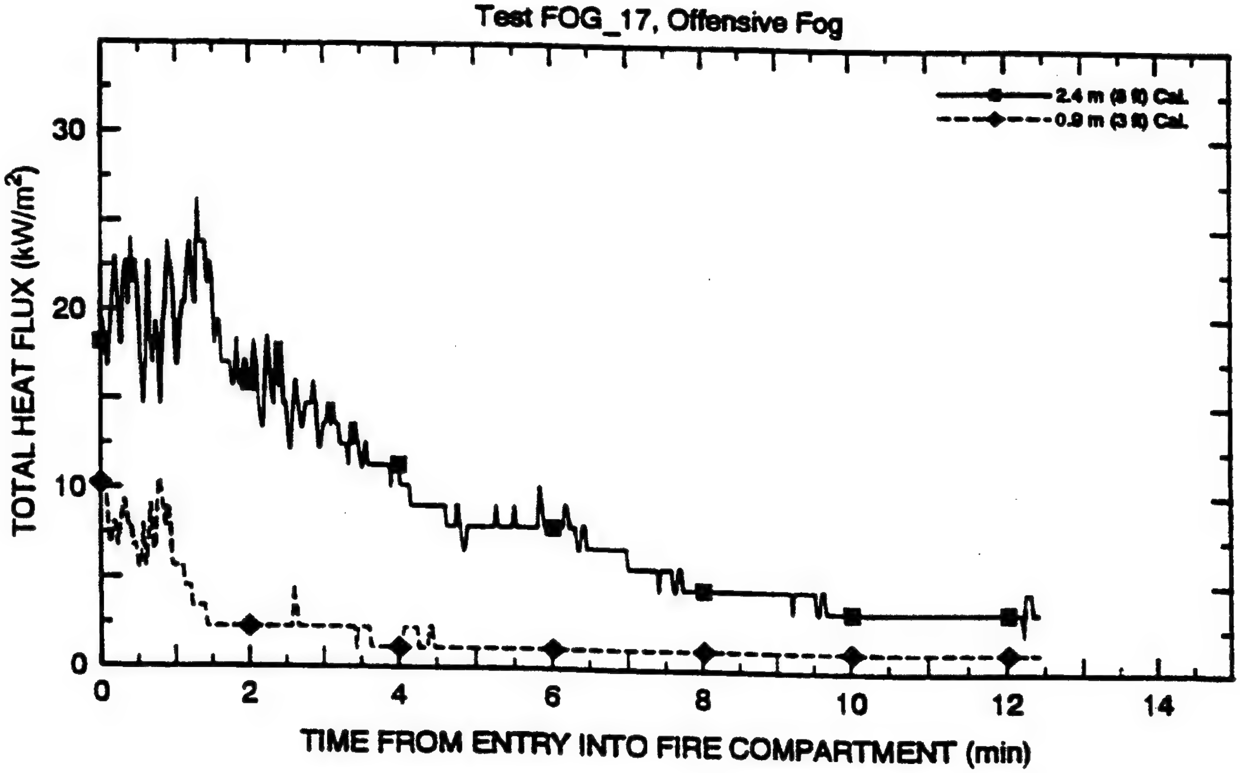


Fig. 35 - Total Heat Flux Data for FOG_14 and FOG_17 (PEB team)

0.9 m (3 ft) heat flux that approached or meets the heat flux for the 2.4 m (8 ft) calorimeter. This indicates total compartment mixing with steam.

Significant disturbances in the thermal balance did not occur during the offensive fog attack evolutions (FOG_13, FOG_15, and FOG_17). With the RUSSEL team, the initial attack actually cooled the upper layer enough to result in a 14.2 kW/m^2 (1.25 Btu/ft^2 sec) drop in the 2.4 m (8 ft) heat flux level. In contrast, the data for the traditional straight stream tests (FOG_12, FOG_14, and FOG_16) show several instances where the thermal balance was disturbed sufficiently to cause the upward spikes on the 0.9 m (3 ft) heat flux plots. Occurrences were most frequent with the RUSSEL team. The phenomena was slightly different for the PEB test. For this evolution, instead of isolated spikes which quickly subsided, the low level heat flux spikes were not as great in magnitude and were followed by 1-2 minutes where the flux level remained elevated. In any case, the thermal balance was disturbed sufficiently to impose a serious heat and steam threat to the team members.

The total heat flux data can also be used to confirm the trends established by the average overhead temperature data. Again with the offensive fog attack, both the upper and lower heat flux levels showed downward trends throughout the evolution. By comparison, the data for the traditional straight stream attack show total heat flux values that either remained steady or increased from the values at the time of entry into the compartment.

The wood crib temperature data is the best indicator of total extinguishing capabilities. Figures 36-38 present a side by side comparison of this data for the traditional straight stream and offensive fog attack evolutions of the RUSSEL, the all female, and the PEB teams respectively. It can be seen from this data that, in general, the offensive fog tactic resulted in an immediate and significant reduction in temperatures in all three cribs. The exception to this is the data for the all female team, which show reflashes in crib #1 on two occasions. In comparison, the traditional straight stream tactic resulted in temperature reductions only in cribs #2 and #3. Crib #1 maintained its temperature and within 1-2 minutes reflashed. This data also clearly shows the reflashes that continued to

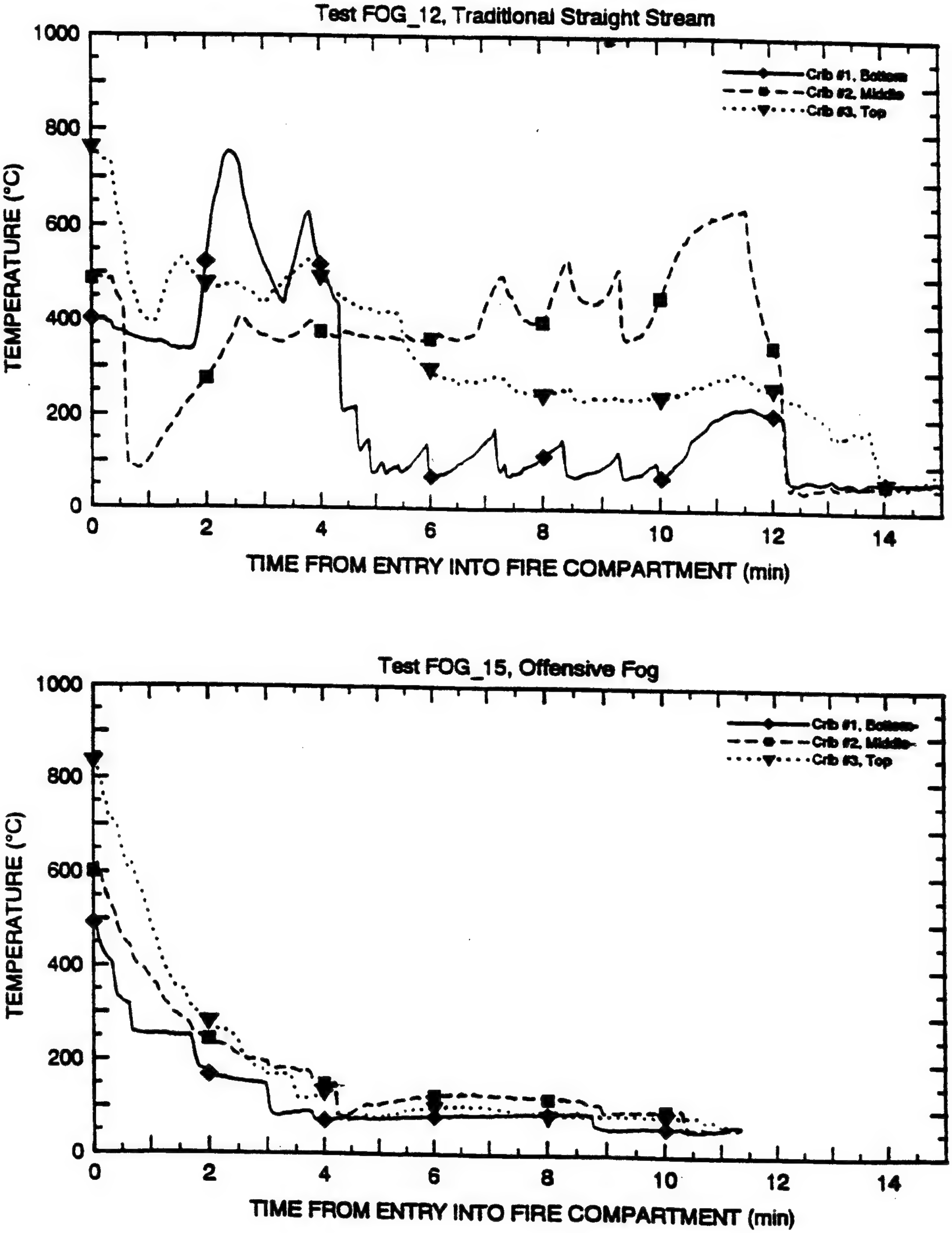


Fig. 36 - Wood Crib Temperatures for FOG_12 and FOG_15 (USS RUSSEL team)

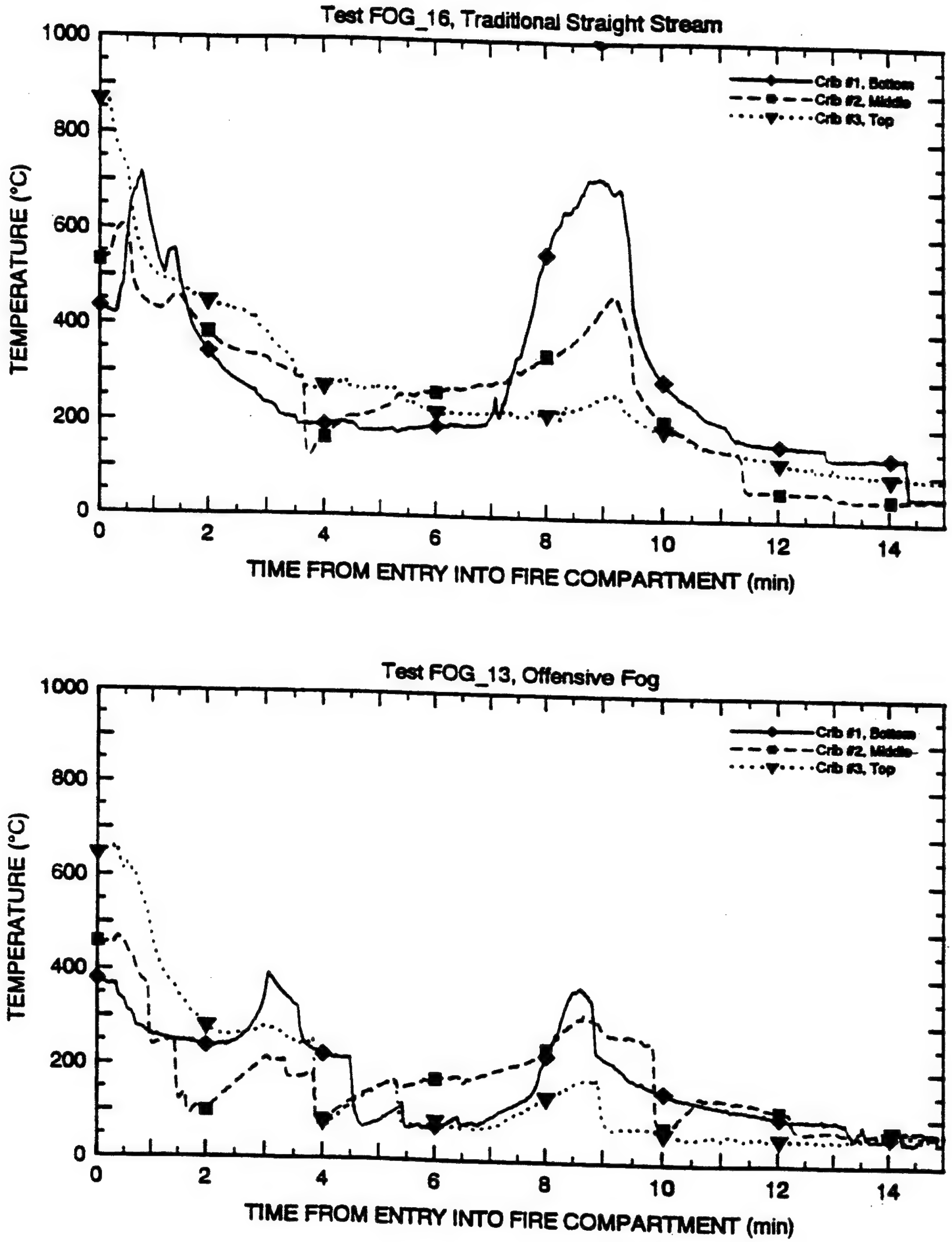
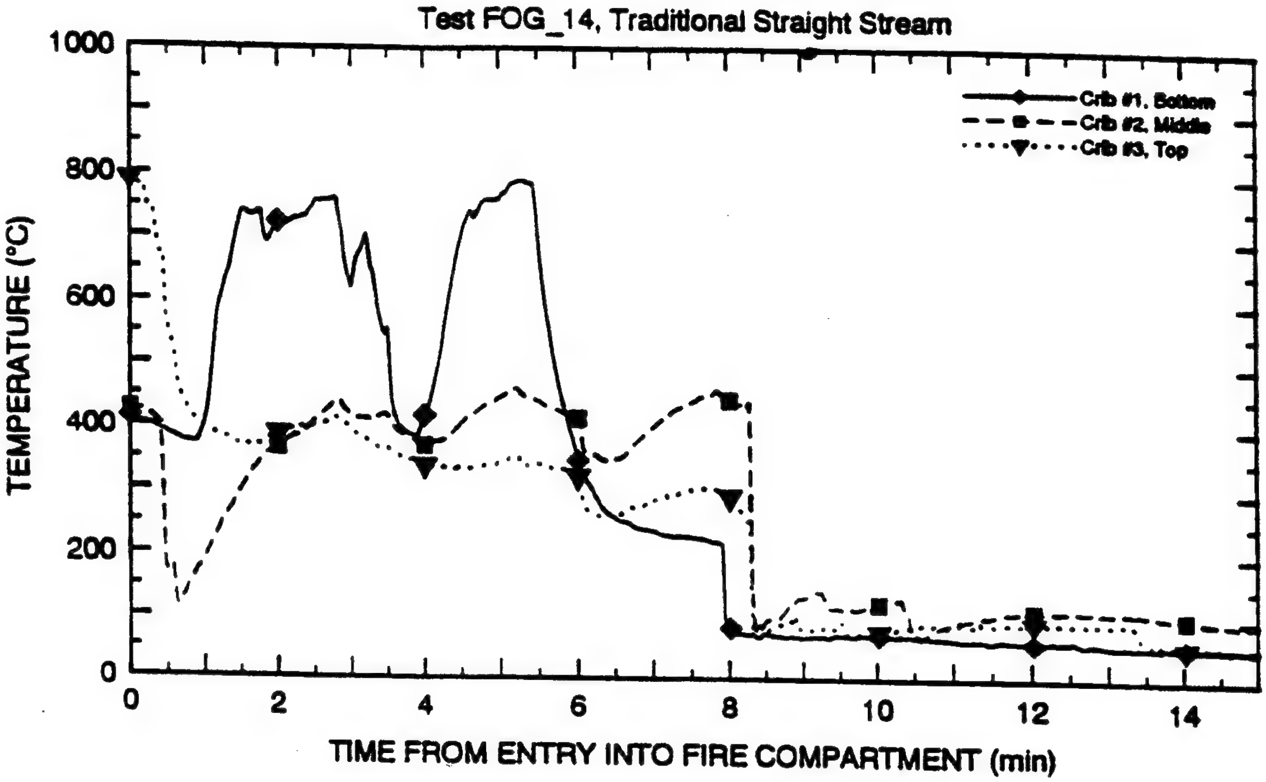


Fig. 37 - Wood Crib Temperatures for FOG_16 and FOG_13 (Female team)



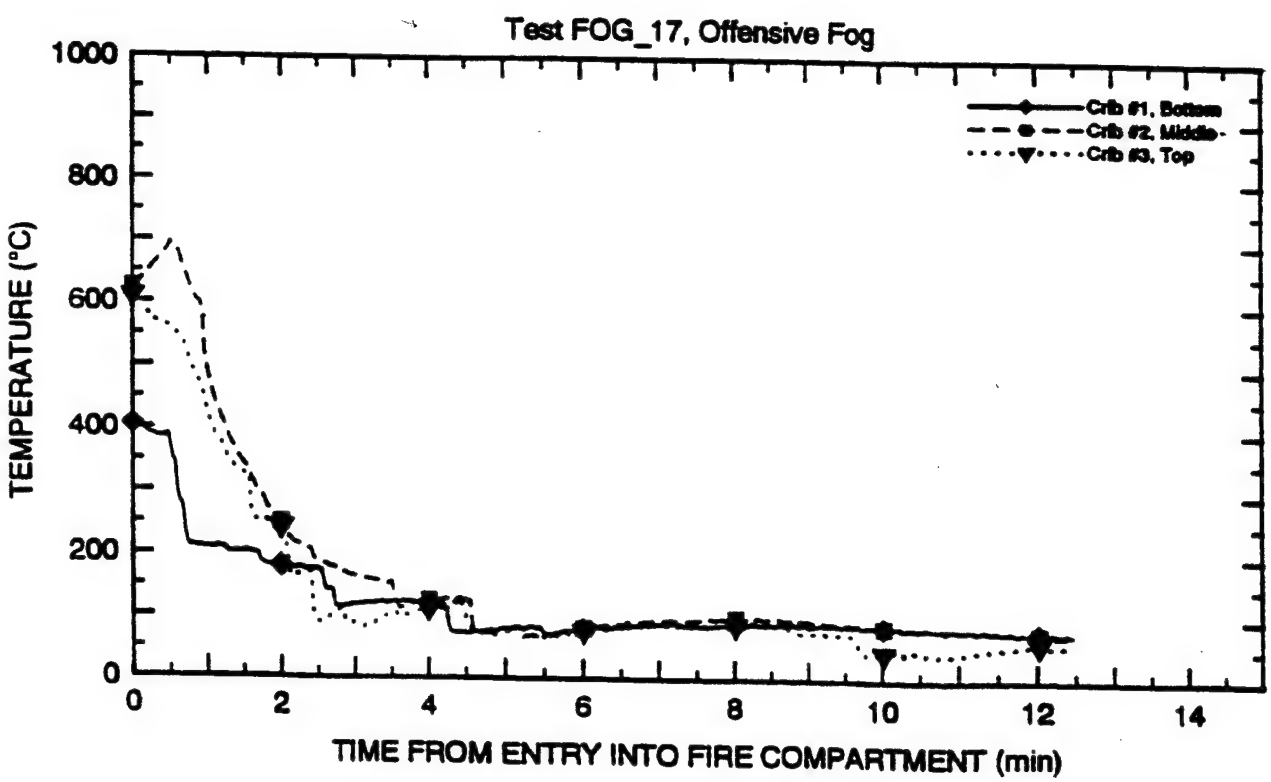


Fig. 38 - Wood Crib Temperatures for FOG_14 and FOG_17 (PEB team)

occur throughout the evolutions. The initial temperature reduction in cribs #2 and #3 is not out of line, given that that was the general direction of the initial attack on the overhead fire. It can be expected that some of that water fell to the cribs. The more important trend is that with the offensive fog attack, even with the fog stream not aimed directly at crib #1, the steam that it produced evidently had an extinguishing effect.

The final measure of performance to be considered is total water consumption. This value must be considered in conjunction with the degree of control or extinguishment achieved. Because total extinguishment was never achieved and control was temporarily at best with the traditional straight stream evolutions, analysis of the water flow data is problematic. It is necessary to develop parameters defining when control and extinguishment were achieved. The following definitions were established for this analysis.

- Control time - The time at which the attack team was able to advance forward from their initial attack position and begin applying water directly to the fire sources.

- Extinguishment - The time at which all crib temperatures were reduced below 125°C (257°F), there was no visible flaming, and there were no subsequent reflashes reported.

Table 15 presents the results based on the above evaluation criteria. These data do not show an advantage to either method. The PEB team was the only one able to achieve control (as defined above) with both the offensive fog and the traditional straight stream tactics. The quantity of water required to achieve this level of control varied by only 11 L (3 gal) between the two tests. The extinguishment data better demonstrates the benefits of the offensive fog tactic, which is not necessarily water use management, but rather more efficient use of the water applied. Even though approximately the same amount of water was used to achieve control, the water used for the offensive fog attack allowed the team to go on to achieve extinguishment. This was also true for the RUSSEL team.

Table 15. Amount of Water Used to Achieve Control and Extinguishment

Attack Team	Attack Method	Test No.	Control			Extinguishment	
			Time After Entry (min.)	Water Used L (gal)	Average Overhead Temperature °C (°F)	Time After Entry (min.)	Water Used L (gal)
RUSSEL Team	Offensive Fog Traditional Straight Stream	FOG_15 FOG_12	0:54 N.A.	42 (11) -- ----	405 (761) --- -----	4:15 N.A.	341 (90) ____
All Female Team	Offensive Fog Traditional Straight Stream	FOG_13 FOG_16	0:57 N.A.	19 (5) ____	430 (806) ____	N.A. N.A.	____ ____
PEB Team	Offensive Fog Traditional Straight Stream	FOG_17 FOG_14	0:58 1:08	34 (9) 23 (6)	430 (806) 447 (836.6)	4:34 N.A.	303 (86) ____

Effect of Obstructions

When the obstructions were removed from in front of the No. 1 and No. 2 fire areas, the challenge to the attack teams was significantly reduced. In this case, a standard direct attack as described in NSTM 555 was possible, given that the overhead fire threat was not overwhelming. For this scenario, both the quantitative and the qualitative data indicate that neither attack method had a clear advantage. The tenability and extinguishment benefits that the offensive fog tactic had previously are offset by the ability to mitigate the threat quickly by applying water to the seat of the fire using a straight stream. The measures of performance used previously to compare the obstructed tests are presented in Figs. 39, 40, and 41 to compare the tactics for the unobstructed tests. (FOG_18 and FOG_19). From these data it can be seen that both evolutions progressed in a similar manner, with the initial attack reducing temperatures and flux levels almost immediately without significantly disturbing the thermal balance in the compartment. The offensive fog tactic required approximately the same amount of water to achieve extinguishment; 170 L (45 gal) as opposed to 207 L (54 gal) for the traditional straight stream.

Low Visibility Scenario

The data for the "low visibility" scenario was presented previously in Figs. 28 and 29. Because there was only one test for this fire threat, and both attack methods were used at various times during the evolution, it is difficult to draw conclusions about the results. Control of both the overhead threat and the fire sources was maintained throughout the evolution. The wood crib and average overhead temperatures show that the initial offensive fog attack had the same cooling and extinguishing effect seen with the growing/steady state fire threat. The total heat flux data indicates that there may have been some minor disturbances in the thermal balance, but the 0.9 m and 2.4 m (3 ft and 8 ft) flux levels were so close together that the layer was probably fairly uniform to begin with.

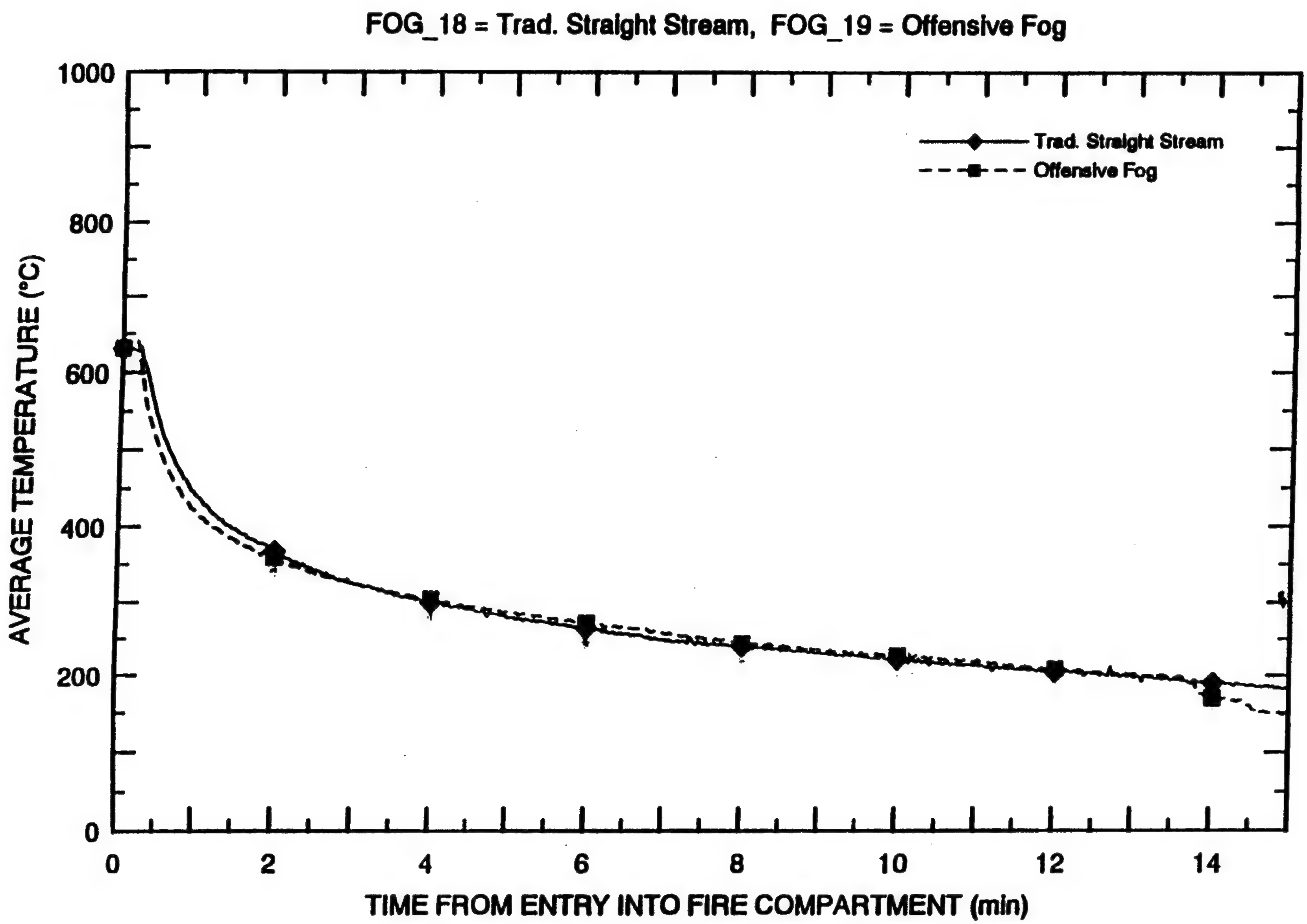
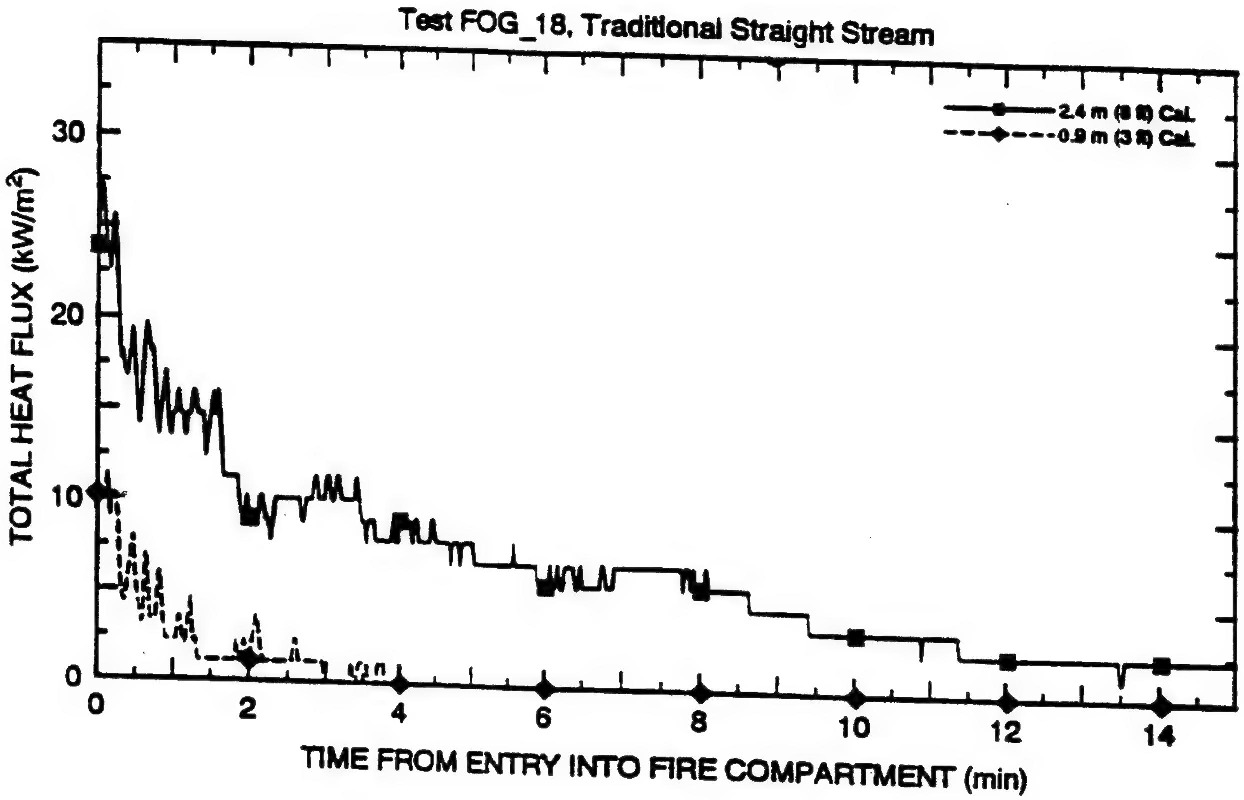


Fig. 39 - Comparison of average overhead temperatures for FOG_18 and FOG_19



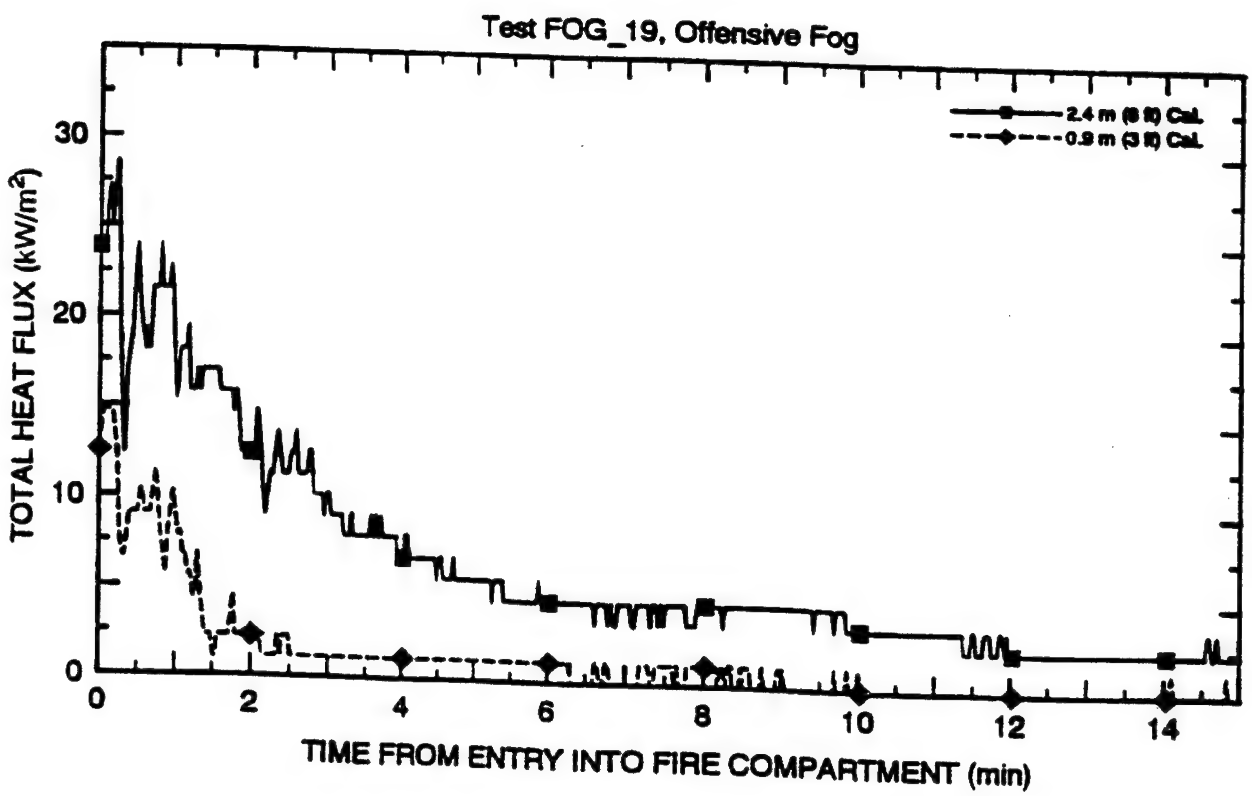
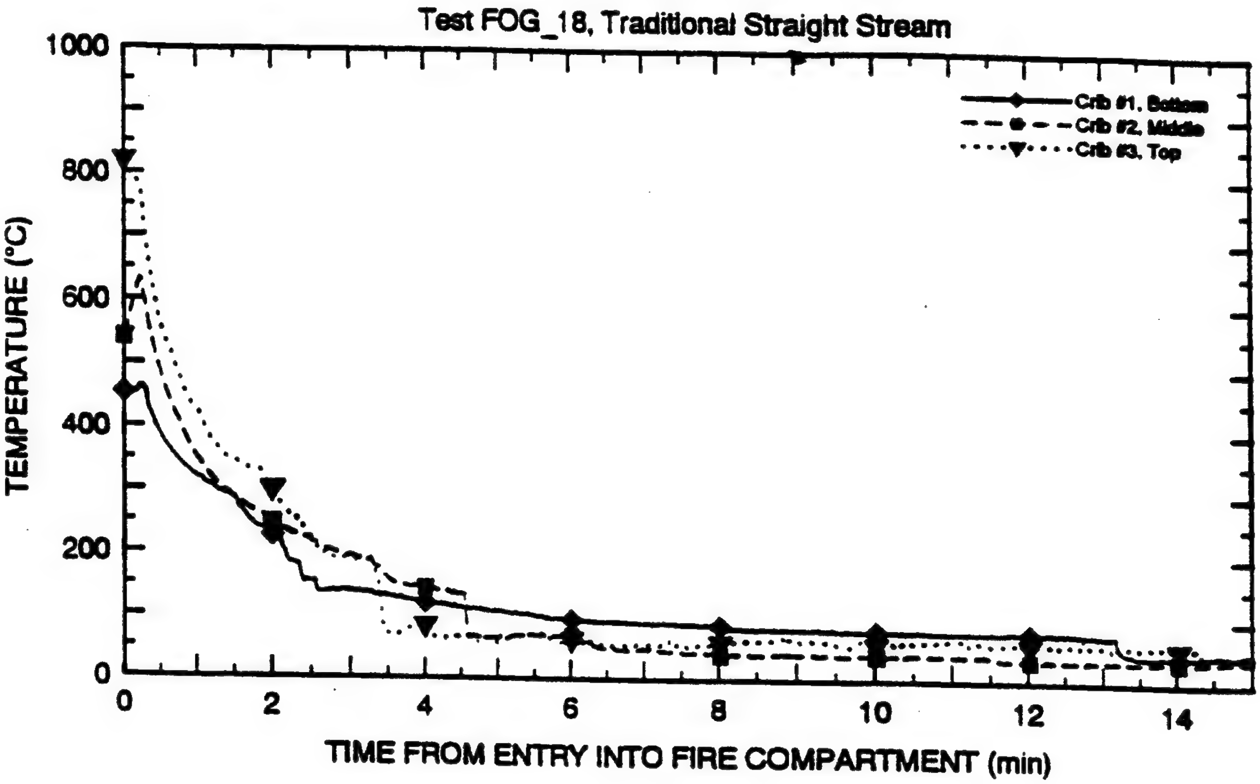


Fig. 40 - Total Heat Flux Data for FOG_18 and FOG_19



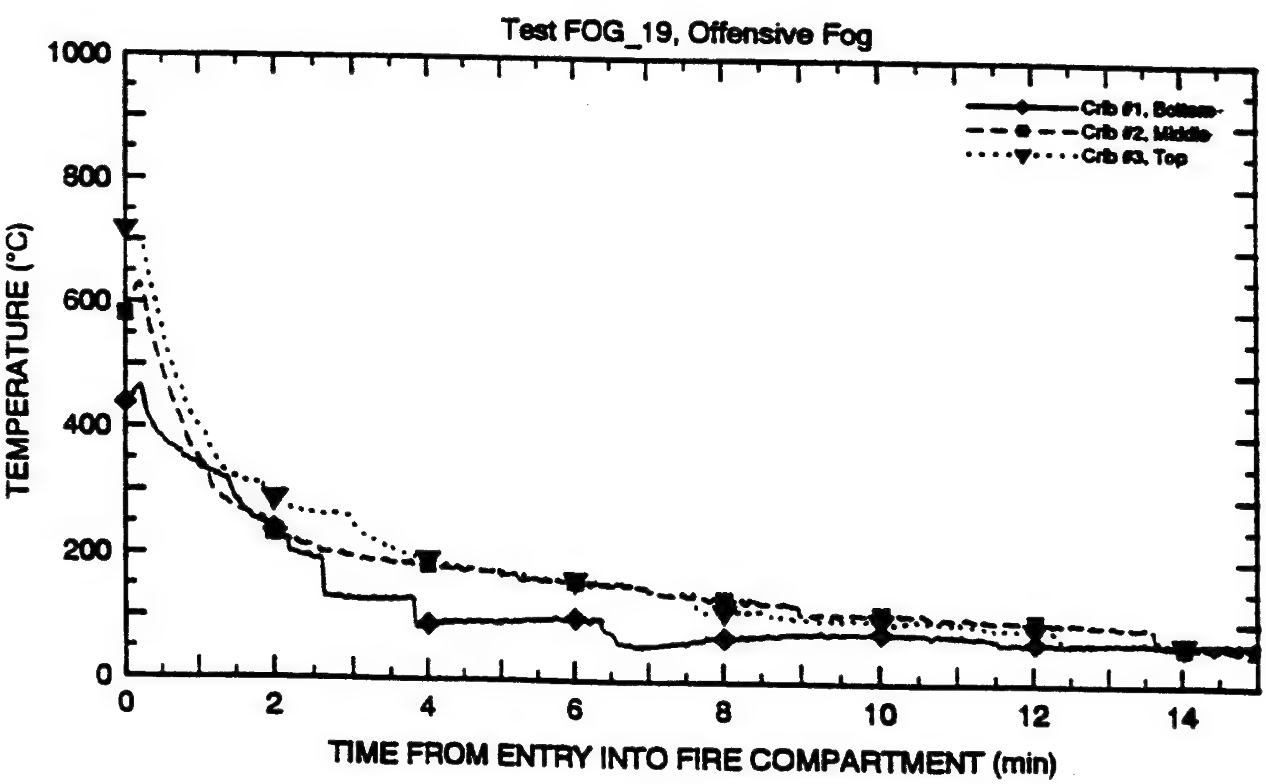


Fig. 41 - Wood Crib Temperatures for FOG_18 and FOG_19

CONCLUSIONS

Based on the qualitative and quantitative data present, the following conclusions can be drawn relative to the use of the offensive fog tactic.

(1) For growing/steady state fire threats, where the seat of the fire is obstructed and the fire is at or near the flashover stage (i.e., overhead temperatures in the range of 400-600°C (752-1112°F)) with flames rolling across the overhead, the offensive fog tactic can be used to improve the fire attack by allowing the attack team to control the overhead threat first.

(2) In situations where the seat of the fire is not obstructed, there were no significant advantages for either the offensive fog tactic or the traditional straight stream tactic.

(3) When applied properly, e.g., a 60° angle fog stream directed at a 45° angle upward at the flaming overhead and discharged in short, controlled burst, 2-3 seconds in duration, the offensive fog tactic can be used effectively to attack and control a fire without disturbing the thermal balance in the compartment. Generally, three bursts will be sufficient to control the overhead fire and to allow the direct attack to continue safely. The exact number of bursts to be used is dependent on the degree of control and knock down achieved. Also, throttling the nozzle to reduce water flow may provide additional benefits by reducing steam production.

(4) Tenability (in terms of heat stress to the firefighters) in the space was improved when the offensive fog tactic was used. Using a straight stream or narrow angle fog directed to the overhead resulted in excessive amounts of hot, penetrating steam. The steam generated by the offensive fog was not as severe and resulted in no burns to the firefighters.

(5) In situations where the source of the fire could not be attacked directly, the offensive fog tactic show better extinguishing capabilities than the traditional straight stream directed off of bulkheads and the overhead.

(6) Use of the offensive fog tactic allows the firefighter to minimize the flashover potential by reducing the overhead temperatures, even though the seat of the fire can not be attacked directly.

(7) The offensive fog method is a simple tactic that even a novice firefighter can utilize. Training time for the test participants was only 15 minutes.

(8) In a low visibility scenario, the offensive fog tactic provides a method for the attack team to control the fire environment until the seat of the fire is located. From the single test conducted, no disadvantages in using the offensive fog tactic were observed.

(9) The need for rapid rotation of attack team members, in particular, the team leader and nozzleman, was again verified.

(10) Additional evaluation of protective equipment, particularly firefighter's gloves, is needed.

(11) Improvements in the tactics and procedures described in NSTM 555 are not filtering down to the fleet; e.g., NSTM 555 describes nozzle throttling techniques for controlling water flow rates, however, the participants (who were using tactics taught at the training schools) did not use this technique until instructed to do so.

(12) White-out of the NFTI in high heat situations is still a problem.

RECOMMENDATIONS

(1) NSTM 555, Section 555-5.3, should be revised to include the benefits of a medium angle fog stream as an offensive tactic when properly applied in a controlled manner. These revisions should include more complete definitions of direct and indirect tactics. NRL will assist in developing those languages.

(2) Section 555-5.3 should be revised to include recommended tactics and procedures for use of the offensive fog method to control growing/steady state fires where the space can still be entered, but the seat of the fire can not be attacked directly.

(3) The basic training courses should be revised to include training on the use of the offensive fog tactic. This training should include live fire scenarios with obstructed fires. Training should also include improved tactics and procedures developed from previous firefighting workshops; e.g., rotation of attack team personnel, throttling of the vari-nozzle to control water usage and techniques to protect exposed skin.

(4) Advanced training classes should include team leader training on evaluation of fire conditions and determination of appropriate attack tactics.

(5) Initiate a project to develop an advanced damage control/firefighting curricula and facility based on the lessons learned on the SHADWELL.

REFERENCES

1. Carhart, H.W., Toomey, T.A., and Williams, F.W., "The ex-USS SHADWELL Full-scale Fire Research and Test Ship," NRL Memorandum Report 6074, revised January 20, 1988, reissued 1992.

2. Naval Sea Systems Command, "Naval Ships Technical Manual, S9086-53-STM-010, Chapter 555, Shipboard Firefighting," NSTM 555, Department of the Navy, Washington, D.C., June 1993.

3. Wong, J.T., Scheffey, J.L., Toomey, T.A., Farley, J., and Williams, F.W., "Results of Fleet Doctrine Evaluation Tests," NRL Ltr Rpt Ser 6180-412.1, 29 June 1992.

4. Toomey, T.A., Williams, F.W., and Farley, J.P., "Preliminary Findings from Collective Protection System (CPS)/Firefighting (FF) Workshop, 6-11 April 1992," NRL Ltr Rpt Ser 6180/433, 31 August 1992.

5. Williams, F.W., Wong, J.T., Farley, J., Scheffey, J.L., and Toomey, T.A., "Results of Smoke and Heat Management/Firefighting Tests," NRL Ltr Rpt 6180/31, 4 February 1993.

6. Williams, F.W., Scheffey, J.L., Wong, J.T., Toomey, T.A., and Farley, J.P., "1993 Fleet Doctrine Evaluation Workshop: Phase I - Class A Fire/Vertical Attack," NRL Ltr Rpt Ser 6180-400.1, 15 September 1993.

7. Scheffey, J.L., Jonas, L.A., Toomey, T.A., Byrd, R., and Williams, F.W., "Analysis of Quick Response Firefighting Equipment on Submarines - Phase II, Full-scale Doctrine and Tactics Tests," NRL Memo Rpt 6632, 10 July 1990.

8. Grimwood, P.T., "Fog Attack," Hoffman, S., ed., FMJ International Publications, Ltd., Redhill, Surrey, UK, 1992.

9. Clark, W.E., "Firefighting/Principles and Practices," Dun•Donnelley Publishing Corporation, New York, 1974.

10. Layman, L., "Attacking and Extinguishing Interior Fires," National Fire Protection Association, Boston, MA, 1960.

11. International Fire Service Training Association, "Essentials of Firefighting," Third edition, Fire Protection Publications, Oklahoma State University, OK, 1992.

12. Williams, F.W. and Toomey, T.A., "Report on Firefighting Tests for Electrical Cables," NRL Ltr Rpt 6180-932, December 1985.

13. Scheffey, J.L., Hill, S.A., Williams, F.W., Farley, J.P., and Toomey, T.A., "1994 Fleet Doctrine Tests - Phase I, CBD Scoping Tests," NRL Ltr Rpt 6180/0542A, in preparation.

14. Williams, F.W., Scheffey, J.L., Siegmann, C.W., "1994 Attack Team Workshop Test Plan," NRL Ltr Rpt Ser 6180/0620.1, 2 September 1994.

15. Havlovick, B., Williams, F.W., and Toomey, T.A., "Ex-USS SHADWELL's (LSD-15) Operational Levels and Casualty Procedures," NRL Ltr Rpt Ser 6180-171, 6 April 1990.

APPENDIX A

Instrumentation Layout

Instrumentation Notes

1. The CO_2 analyzer on the fire compartment low loop (Loop #4, 2-16-0 – 61.0 cm (24-in.) above the deck) was out-of-service for all tests.

2. The pressure transducer connected to the aft sensing lines (2-21-2) lost calibration after test FOG_15. The unit could not be recalibrated. The other transducer showed excessive noise in the signal for all tests.

Table A1. Instrumentation Key

Symbol	Description
A	Audio
V	Camera, arrow indicates direction of view
G	Gas sample (continuous (O_2, CO, CO_2) 24-in. off of deck, and 12-in. below overhead
IR	Camera (infrared), arrow indicates direction of view
IR_T	Cable connections for portable infrared camera
R	Radiometer, at 3 ft and 8 ft in fire area, at 5 ft in GSK area
C	Calorimeter, at 3 ft and 8 ft in fire area, at 5 ft in GSK area
S	Door microswitch
T	Thermocouple tree, starting at 18-in. above the deck and spaced 18-in. apart
T_A	Air thermocouple, 18-in. and 60-in. above deck
T_B	Bulkhead thermocouple (both sides)
T_D	Deck thermocouple (both sides)
T_O	Overhead thermocouple, 6-in. below overhead
U	Ultrasonic water flowmeter
OD	Optical density meter (LED type), 60-in. above deck
T_C	Crib thermocouple, provide three for each location, positioned at bottom, in middle, and 8-in. above top of crib

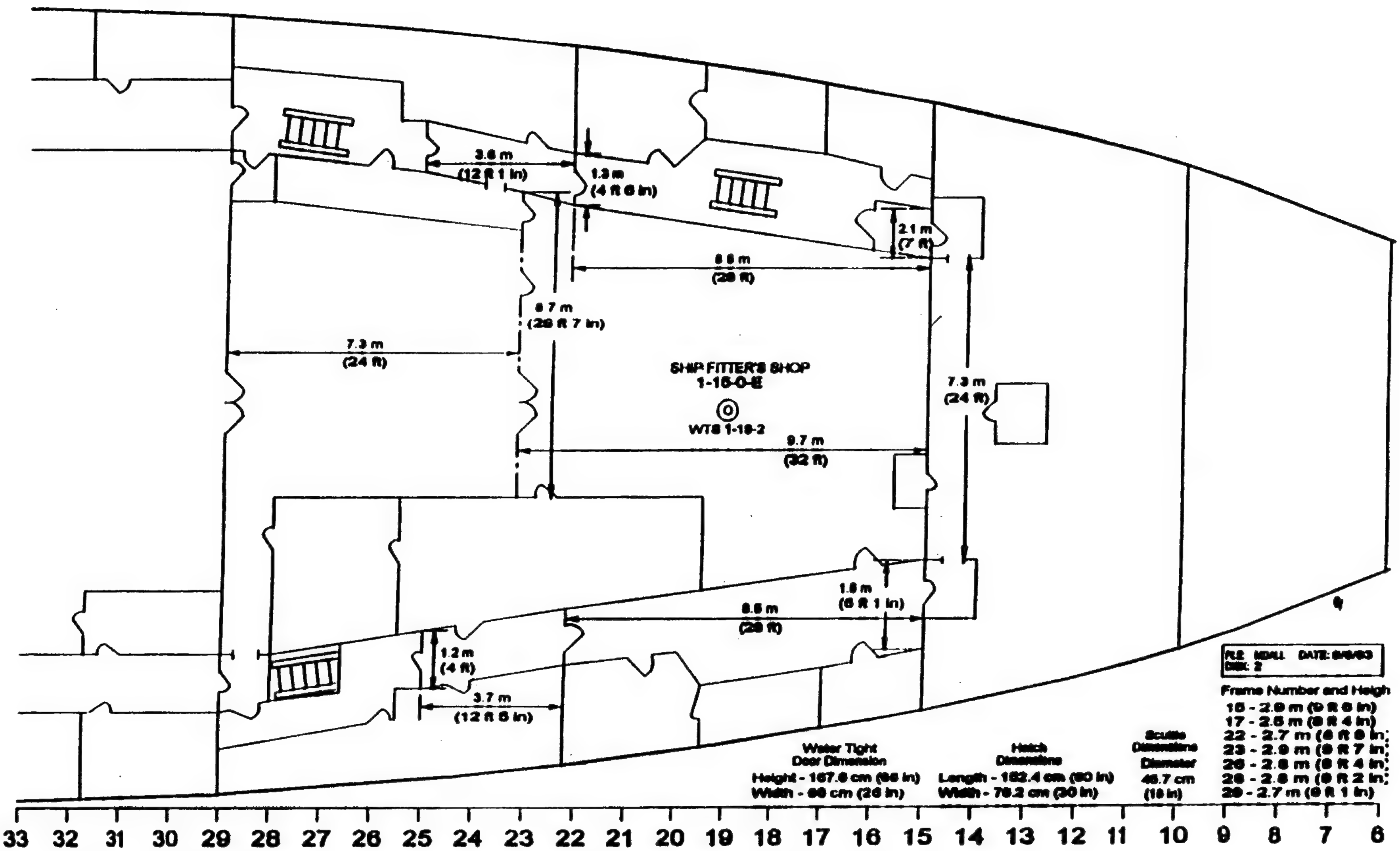


Fig. A1 - Main deck dimensions

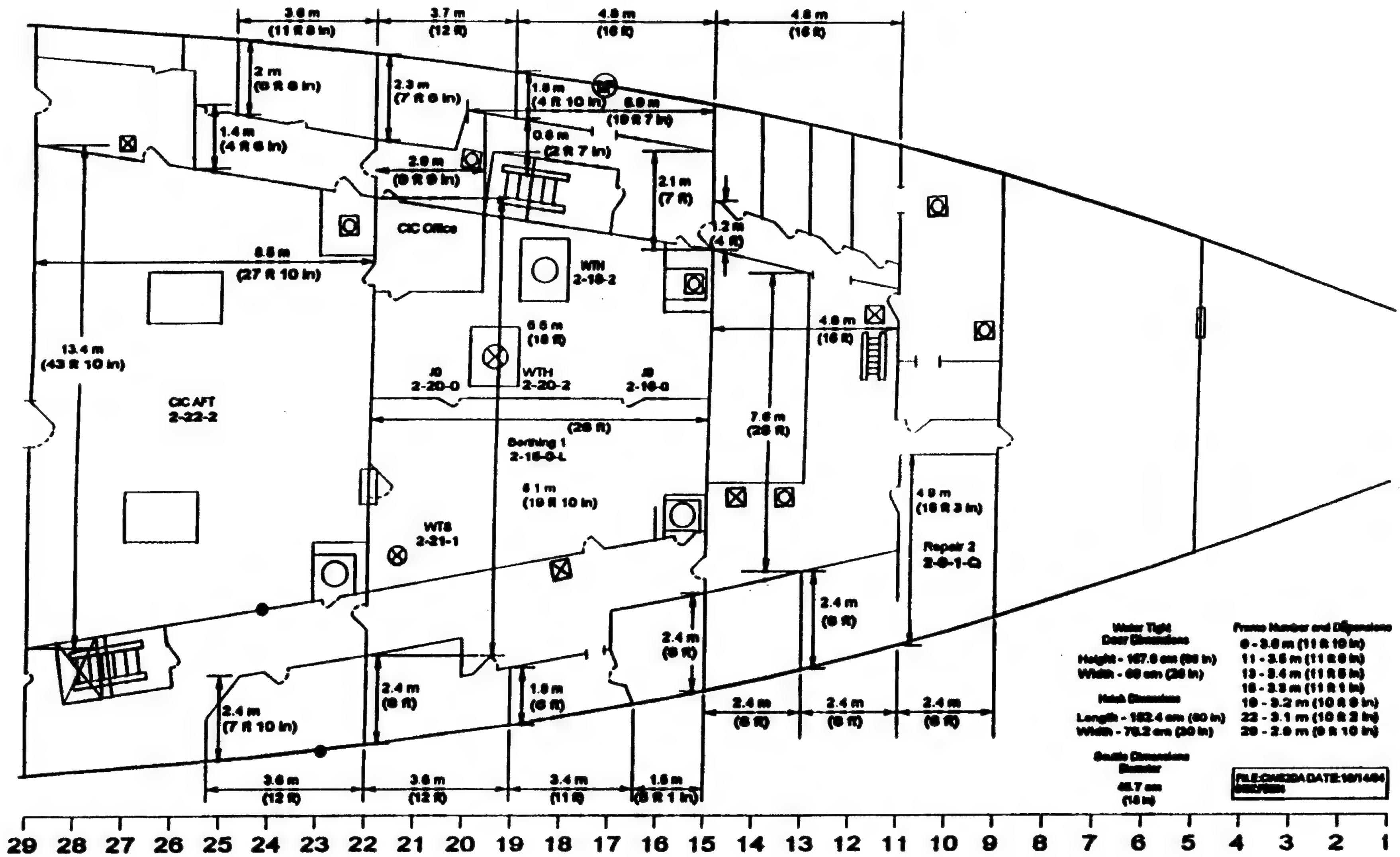


Fig. A2 - Second deck dimensions

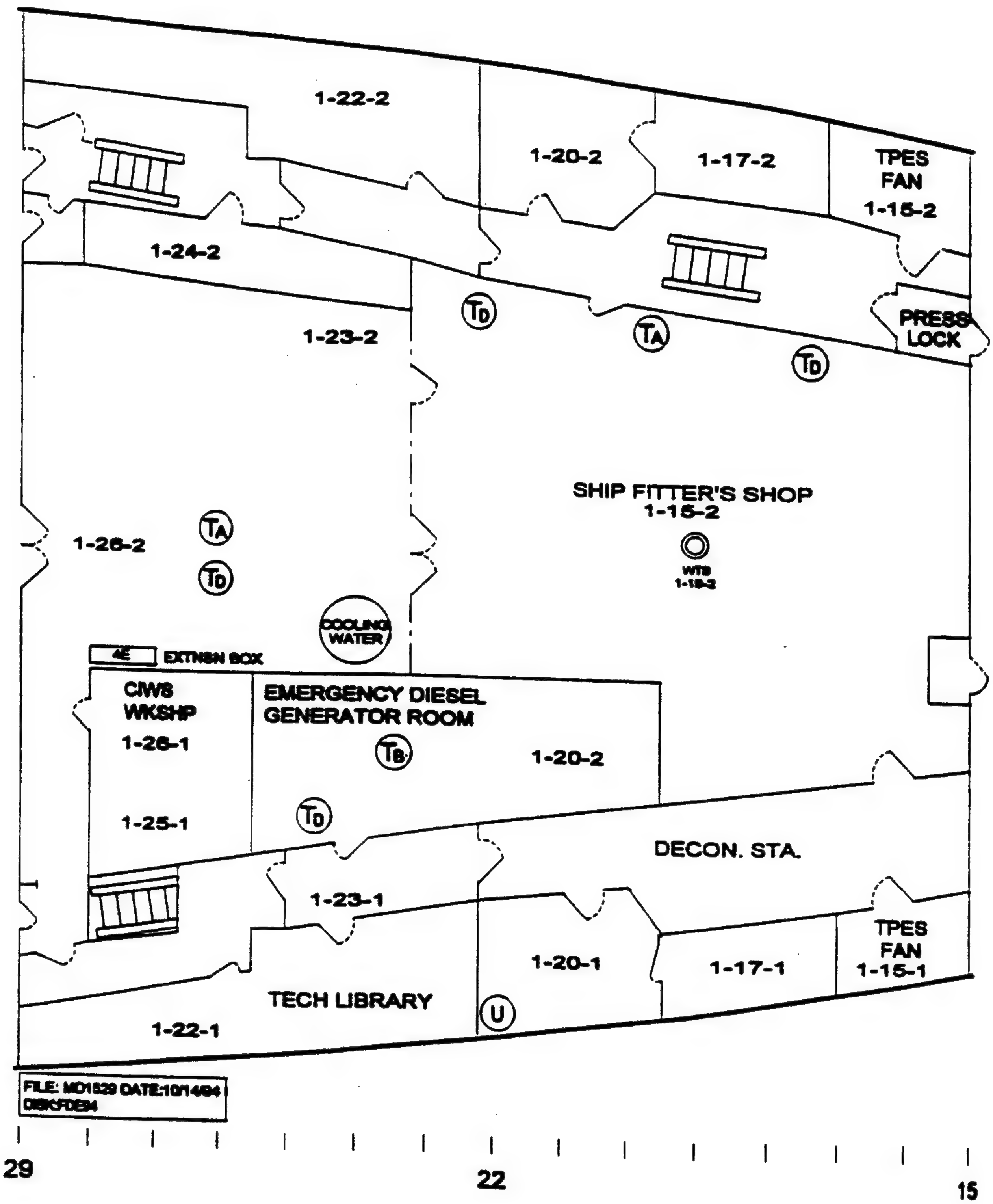


Fig. A3 - First (Main) deck instrumentation layout

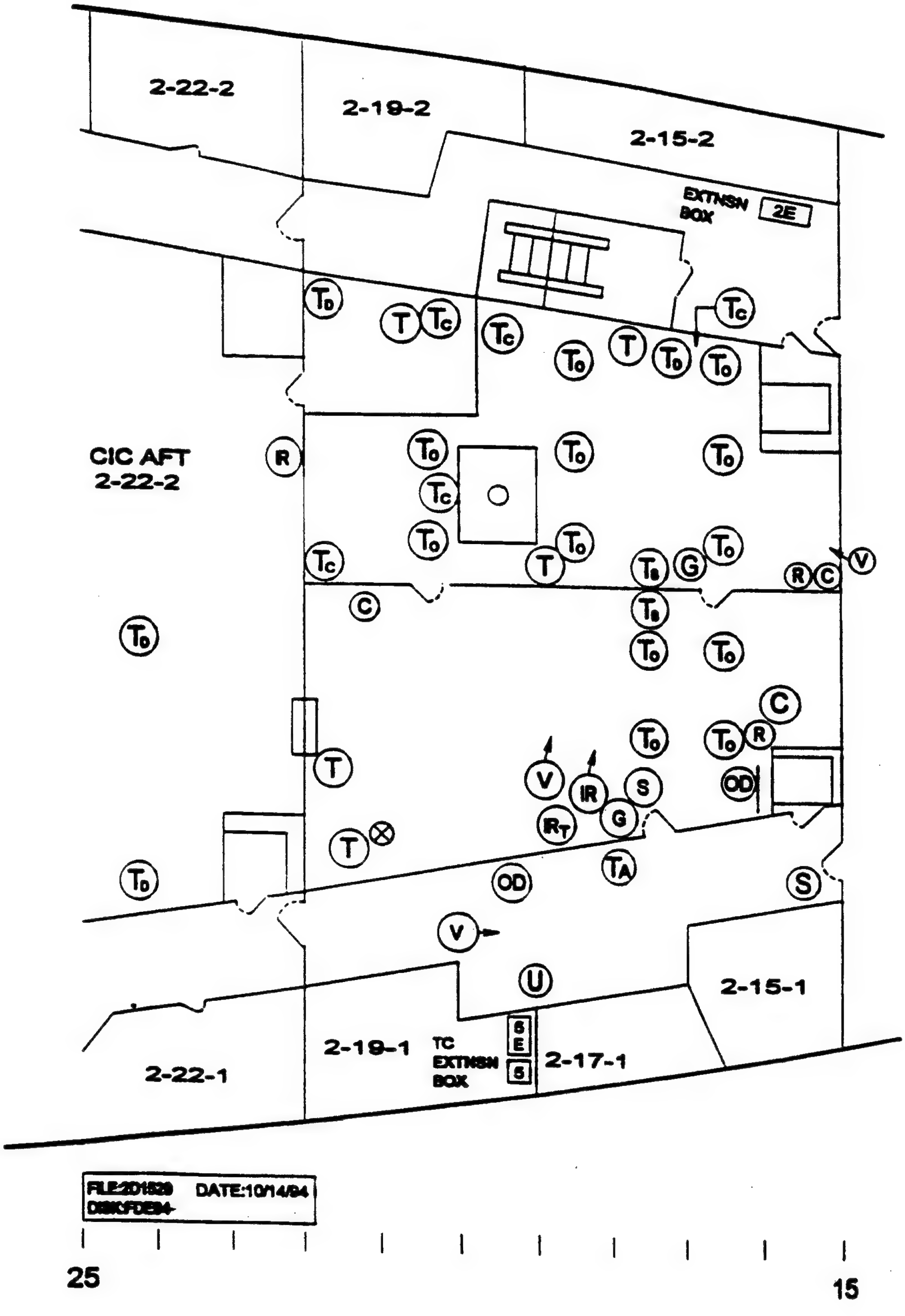


Fig. A4 - Second deck instrumentation layout

APPENDIX B

Representative Data for FOG_12 through FOG_20

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

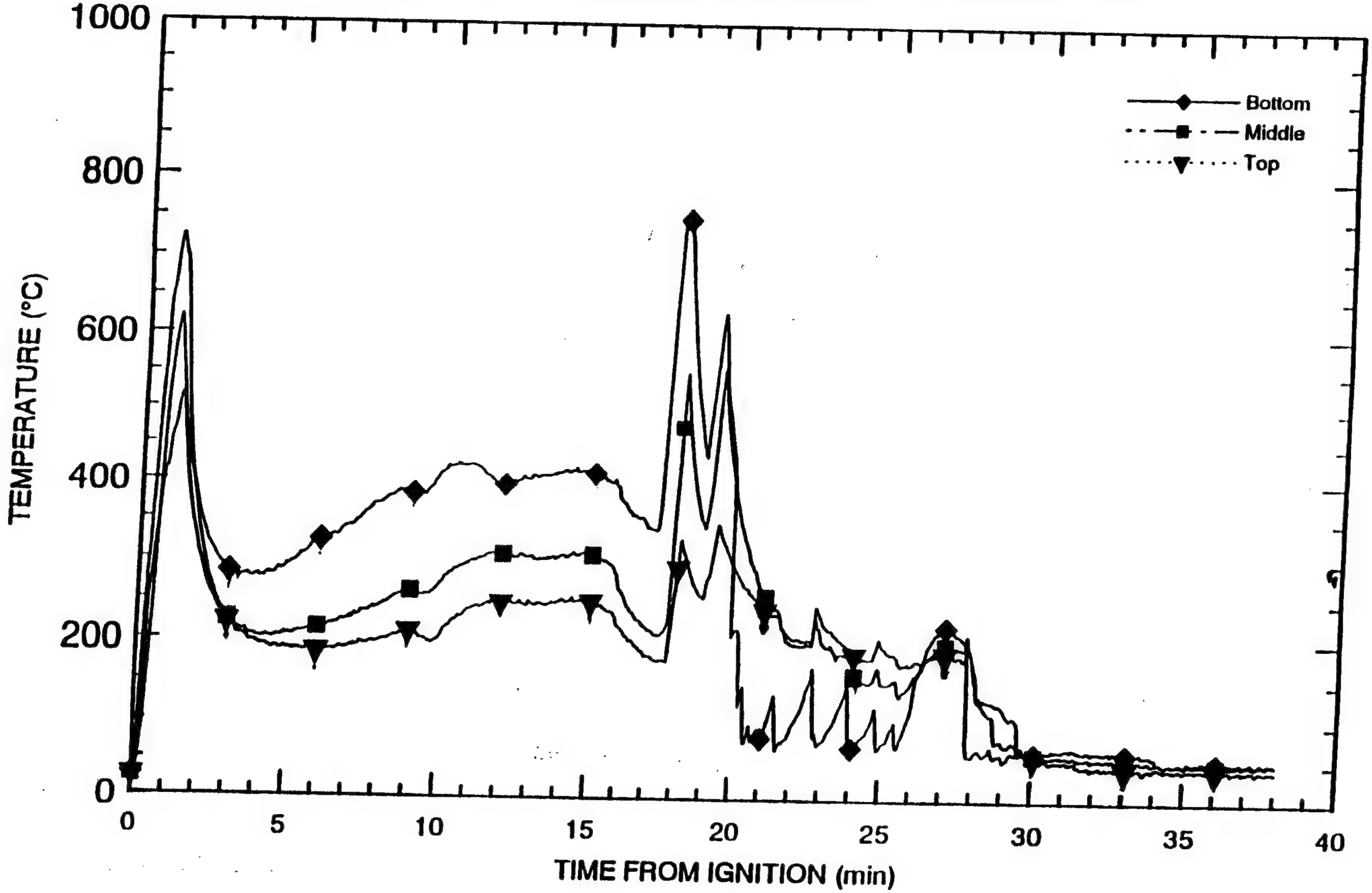


Fig. B1 - Wood crib #1 thermocouples for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

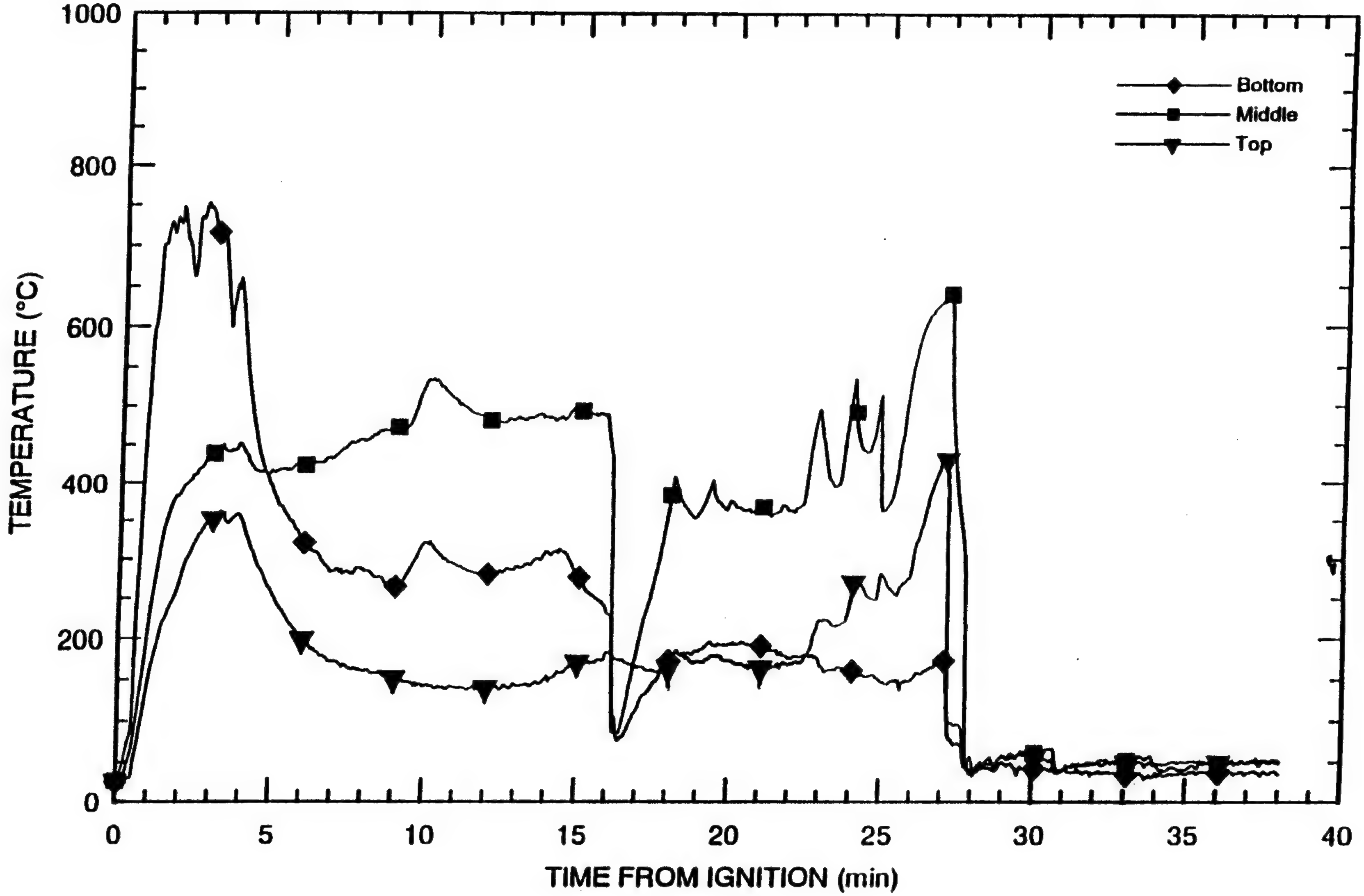


Fig. B2 - Wood crib #2 thermocouples for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

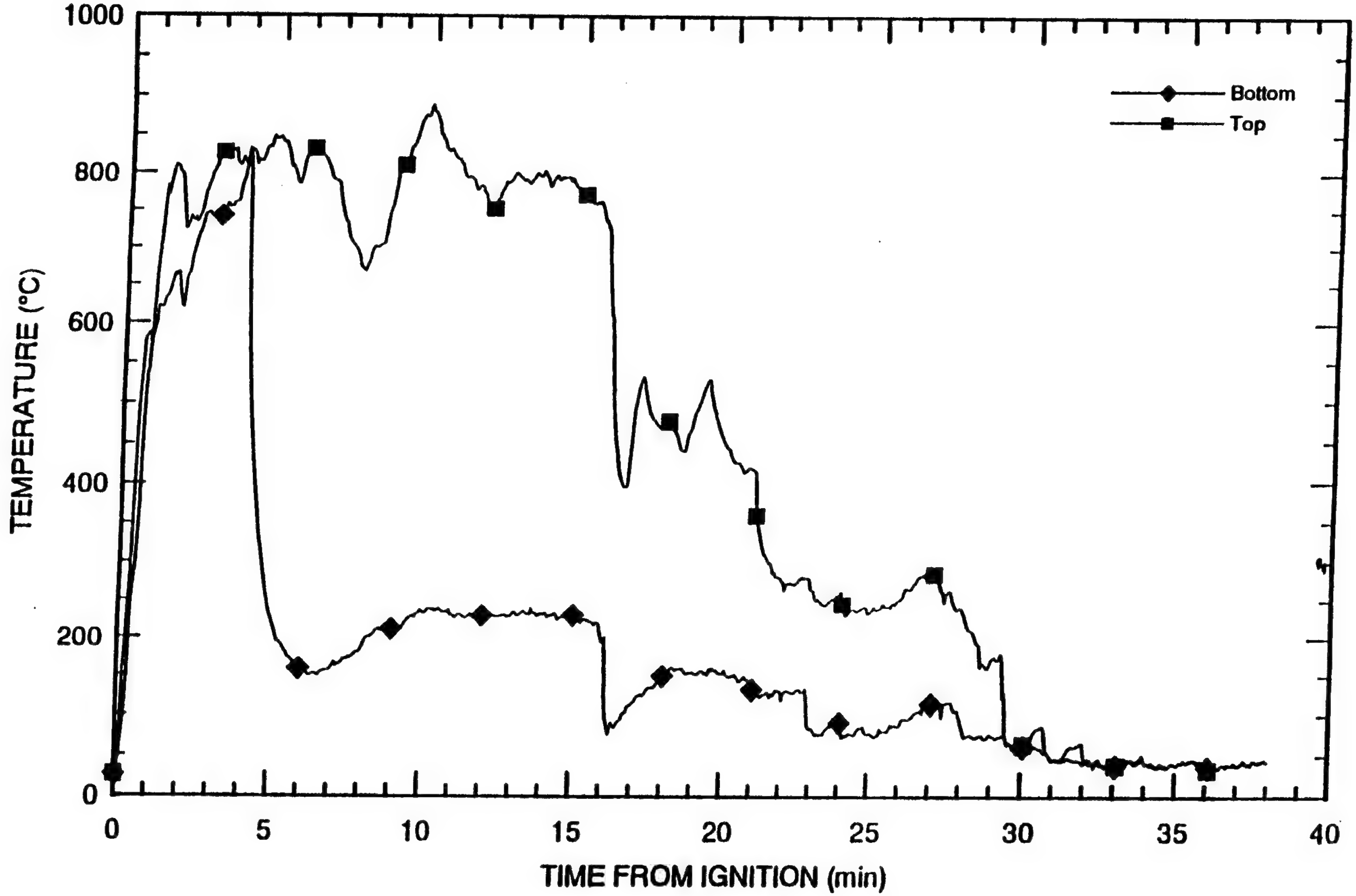


Fig. B3 - Wood crib #3 thermocouples for FOG_12

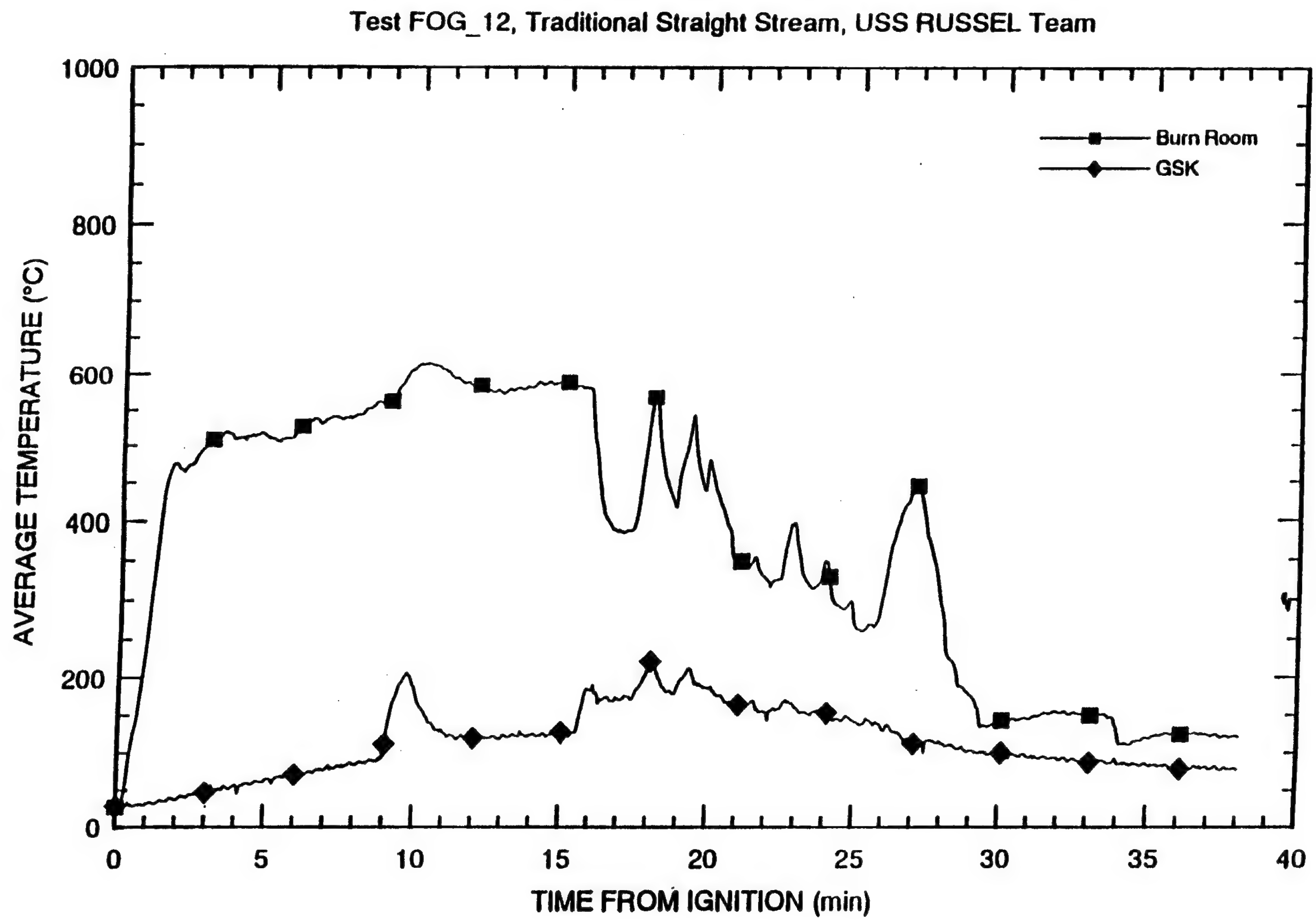


Fig. B4 - Average of overhead thermocouples for FOG_12

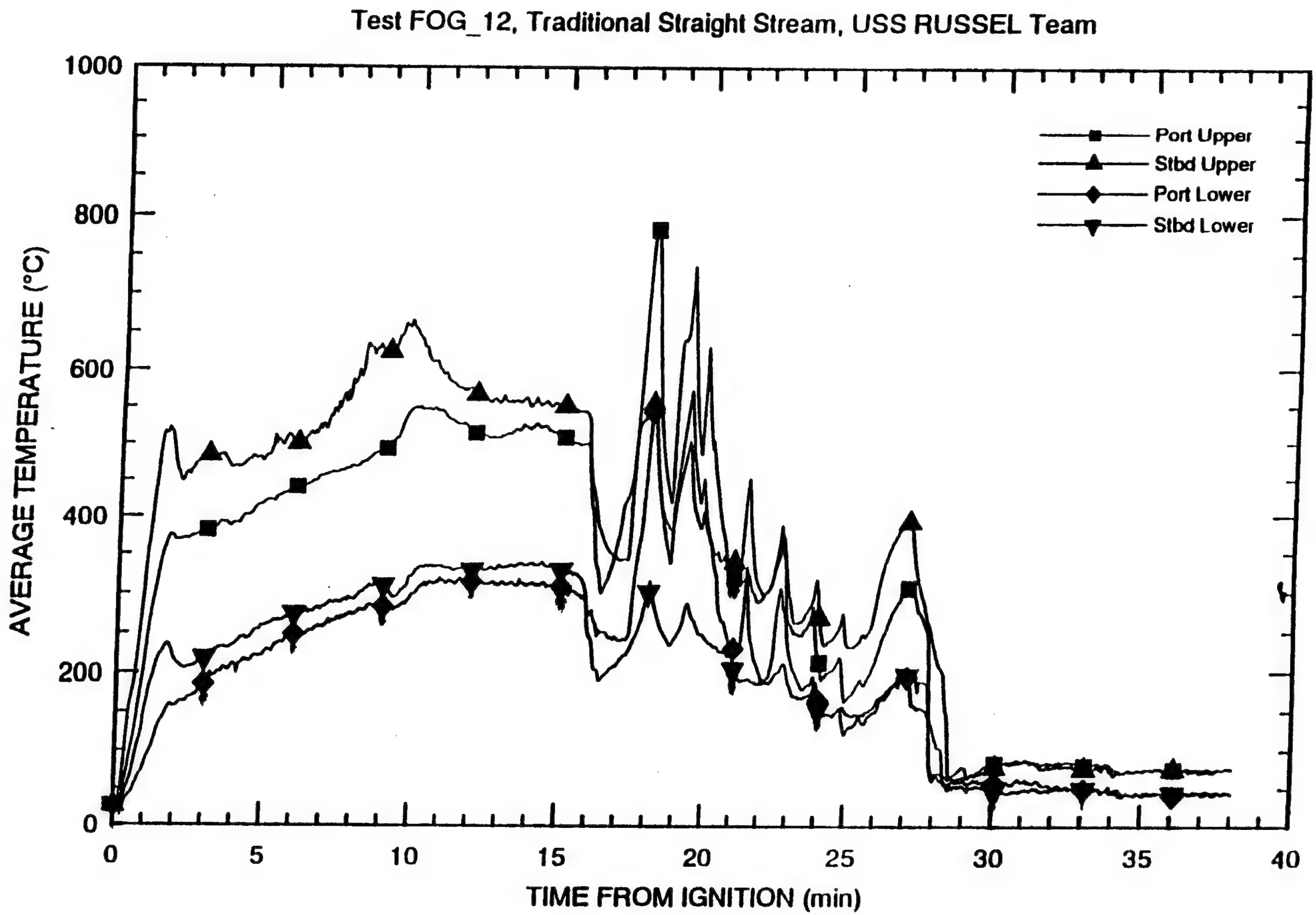


Fig. B5 - Burn room thermocouple string averages (upper vs. lower) for FOG_12

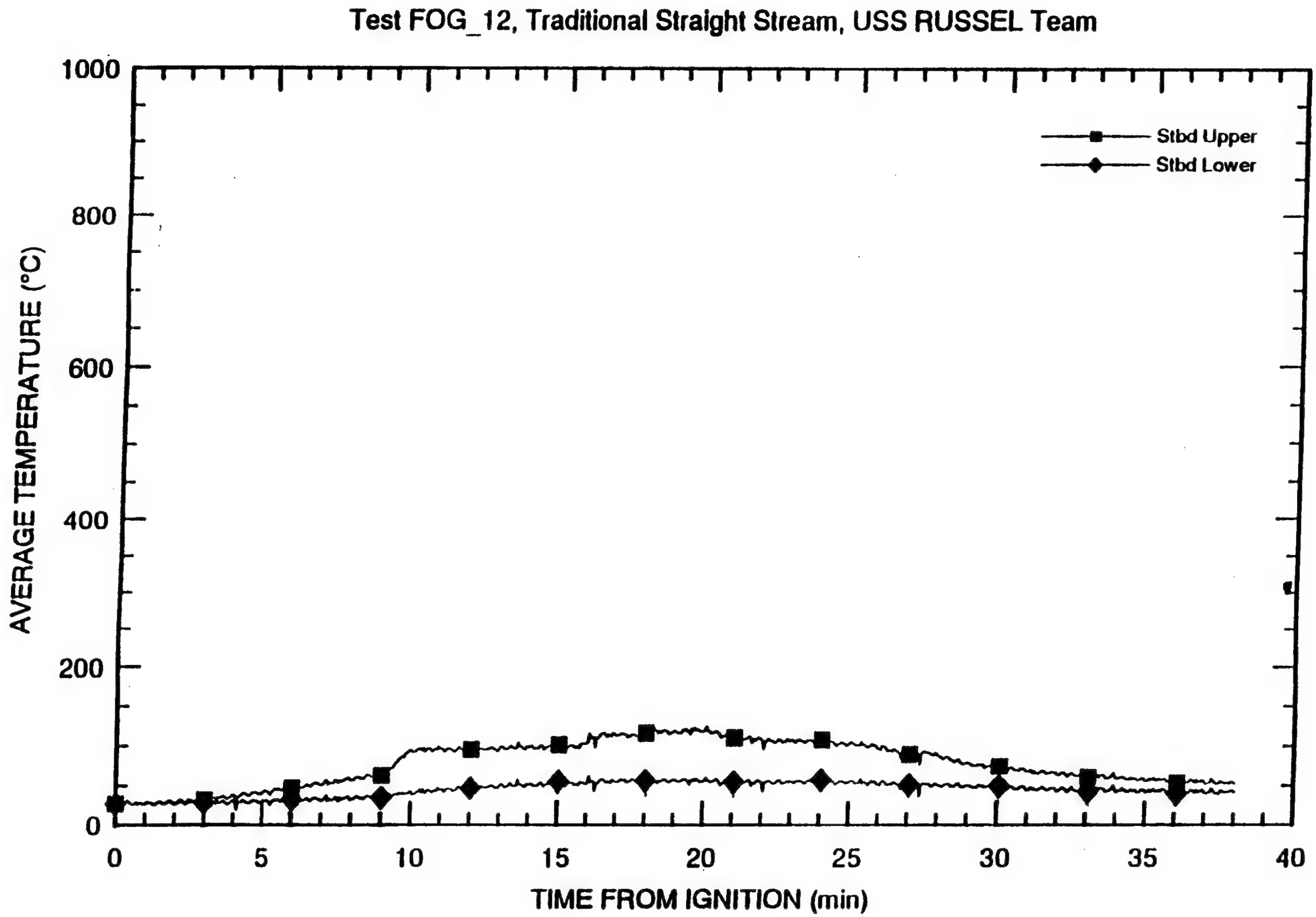


Fig. B6 - GSK thermocouple string averages (upper vs. lower) for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

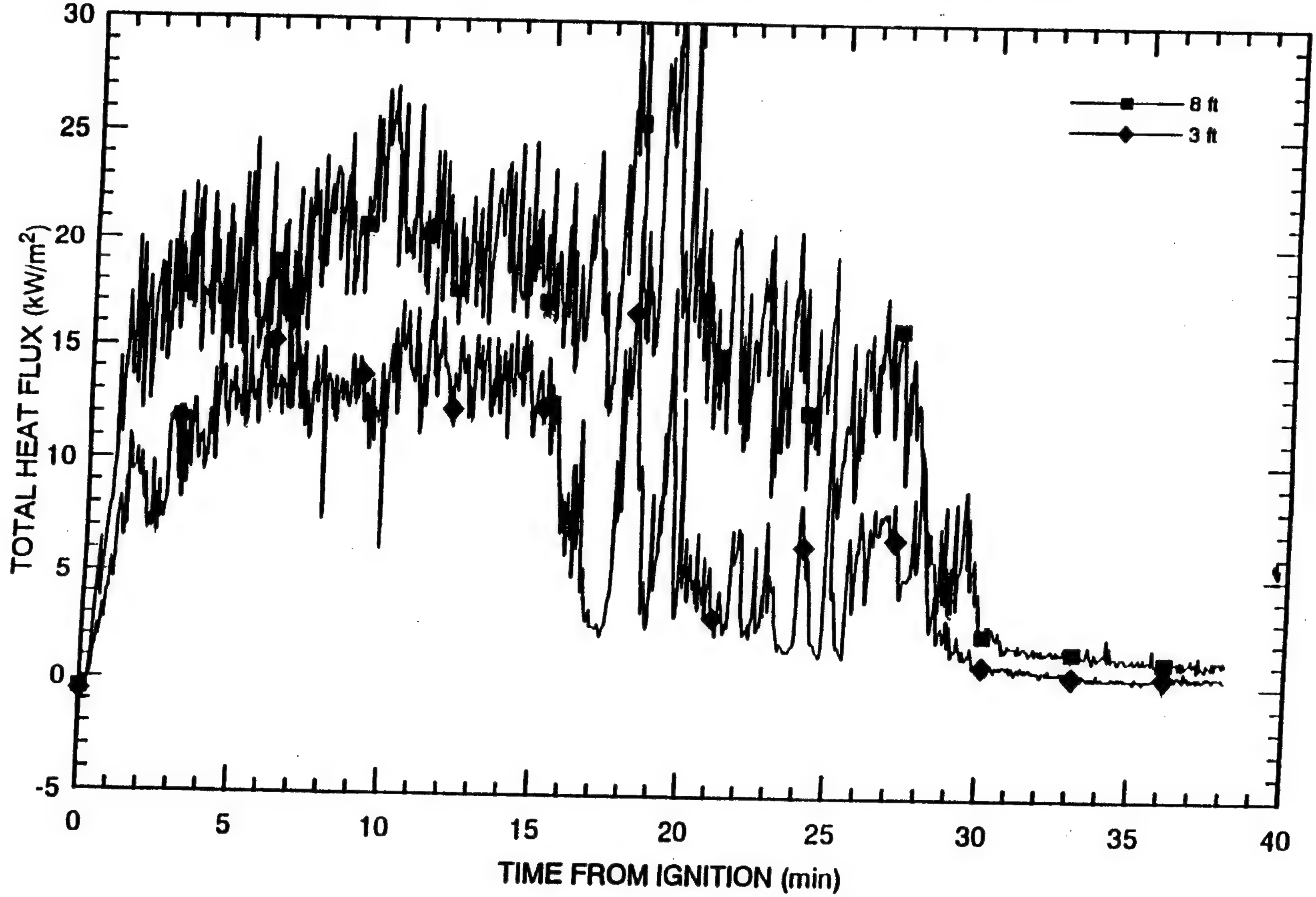


Fig. B7 - Burn room calorimeters for FOG_12

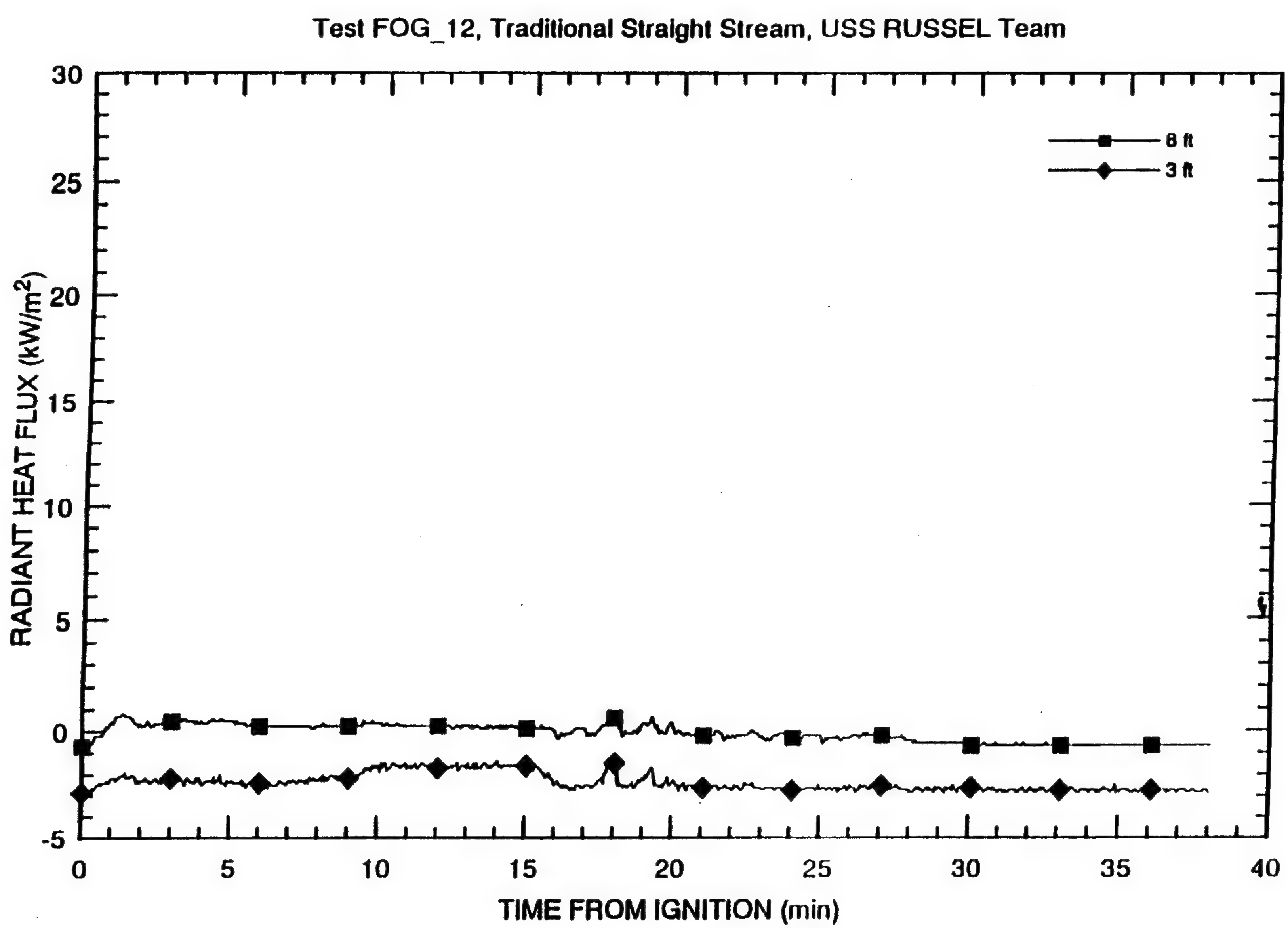


Fig. B8 - Burn room radiometers for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

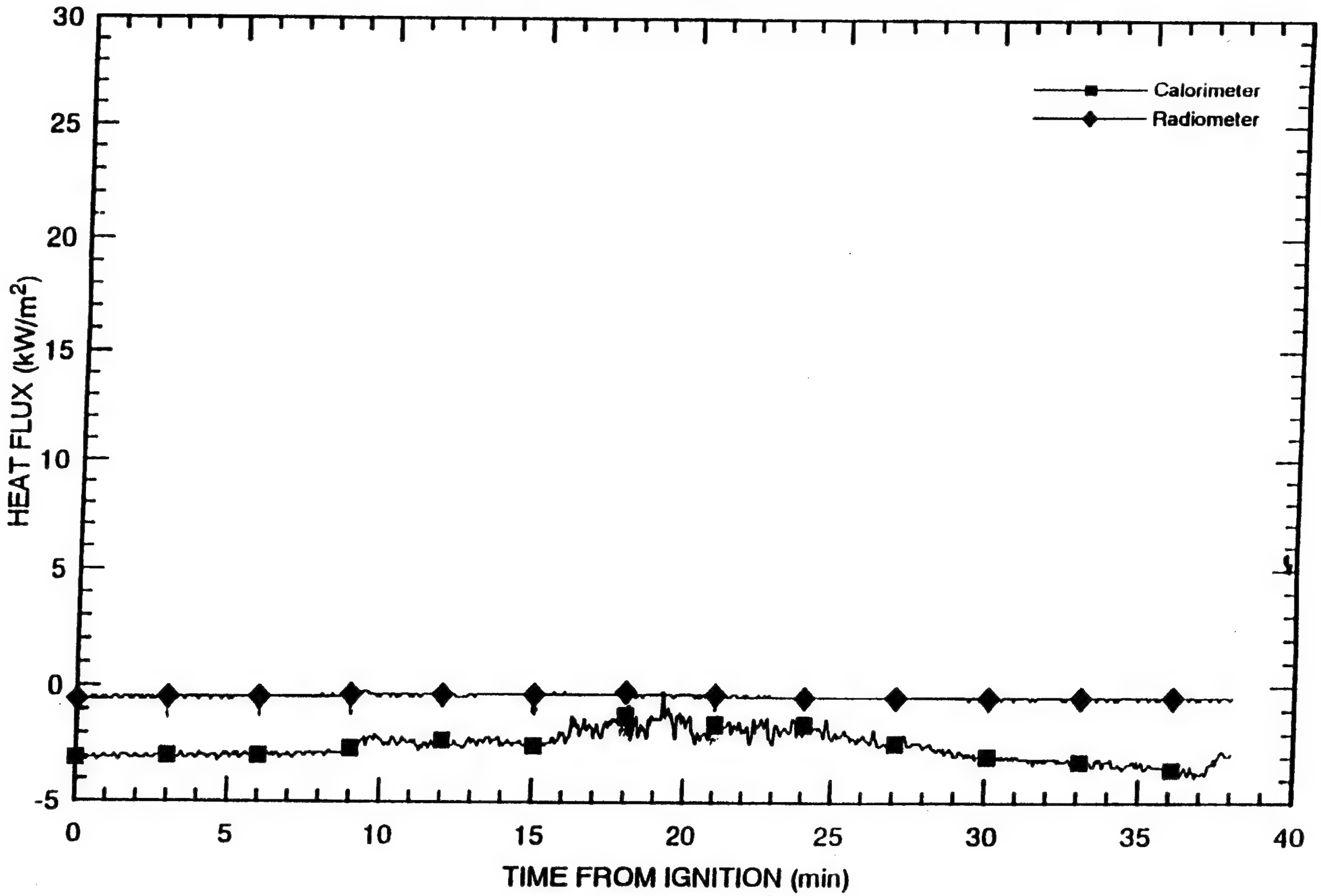


Fig. B9 - GSK radiometer and calorimeter for FOG_12

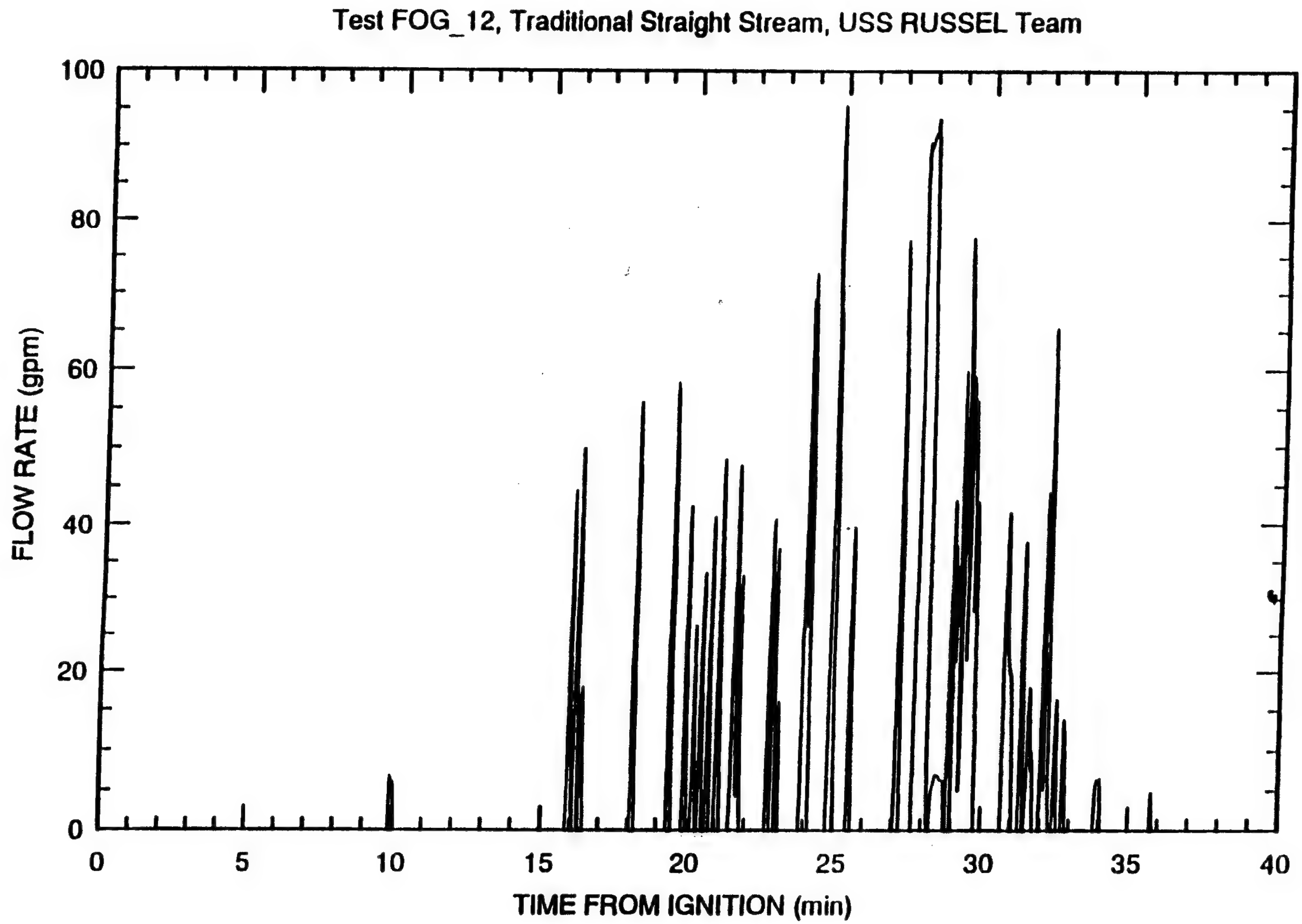


Fig. B10 - Water flow rate for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

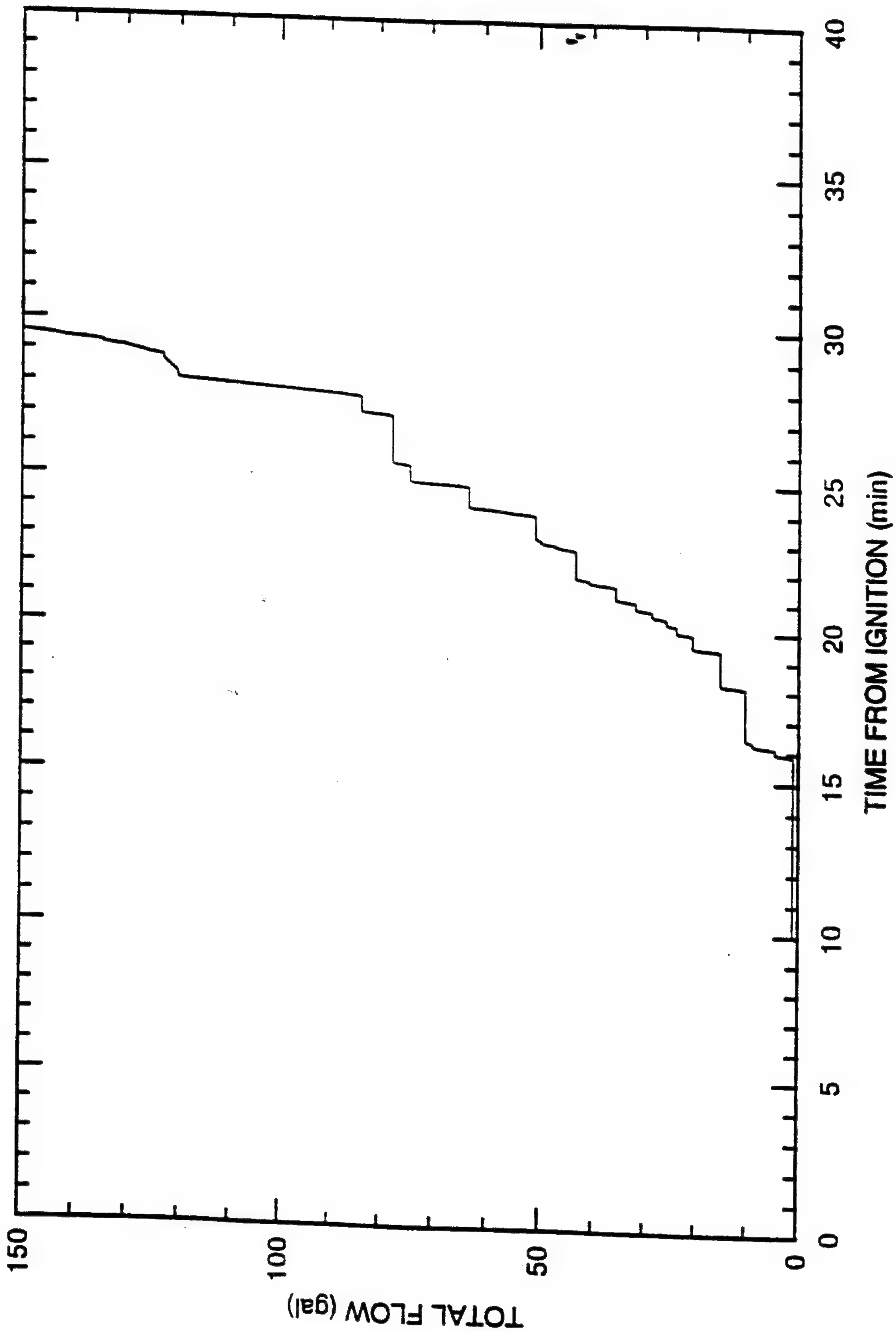


Fig. B11 - Cumulative water flow for FOG_12

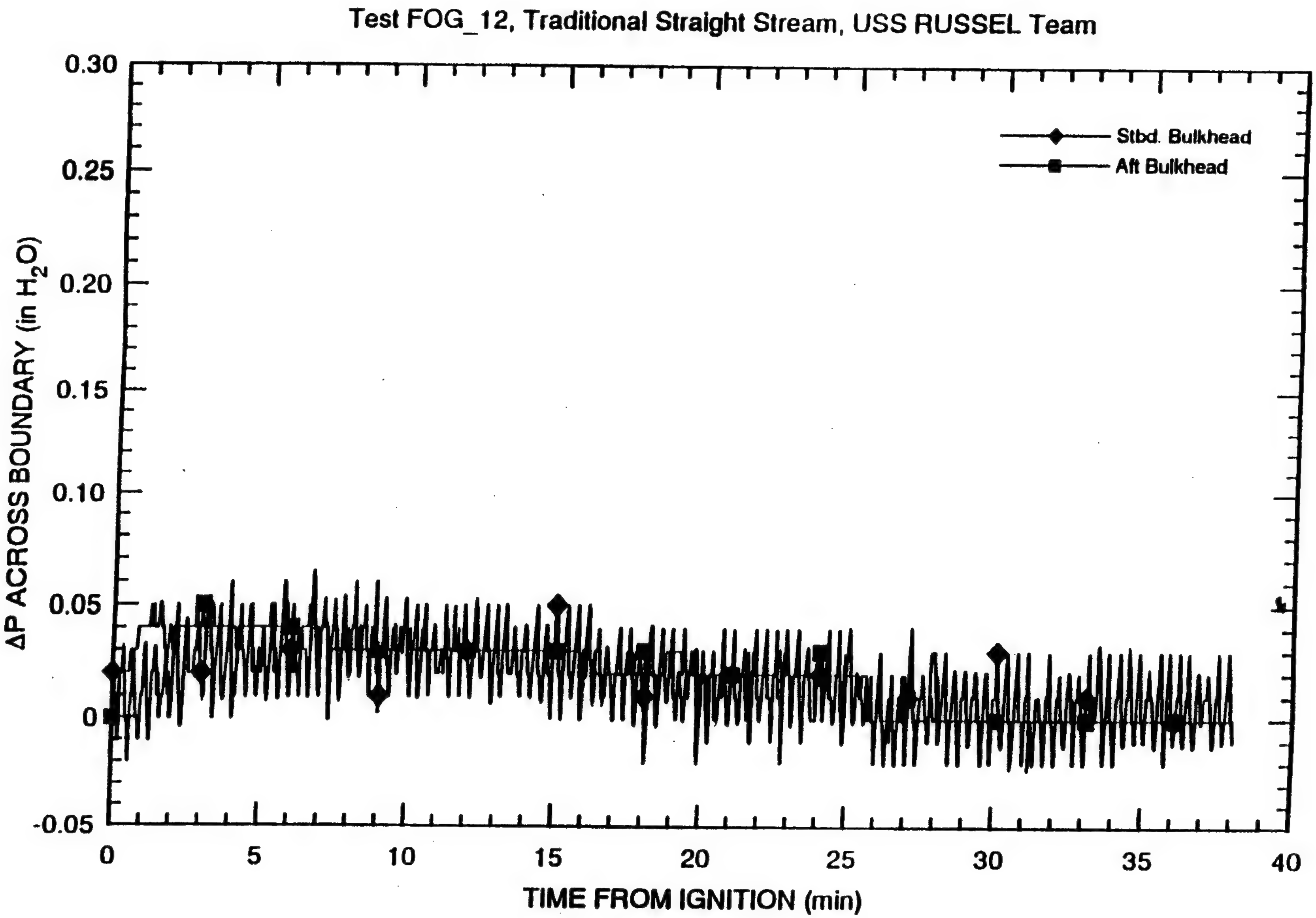


Fig. B12 - Pressure differential across bum room boundaries for FOG_12

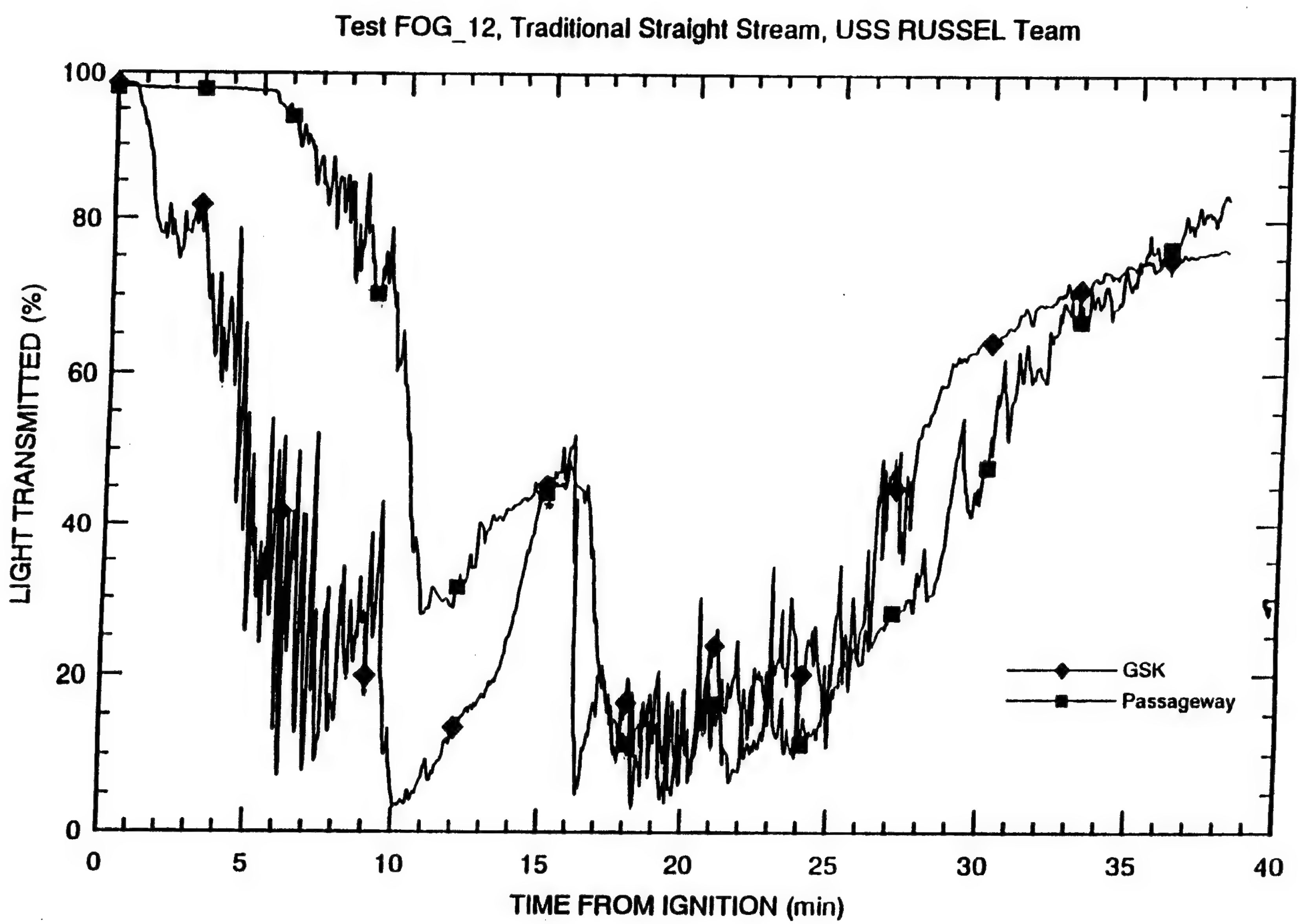


Fig. B13 - Smoke Obscuration for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

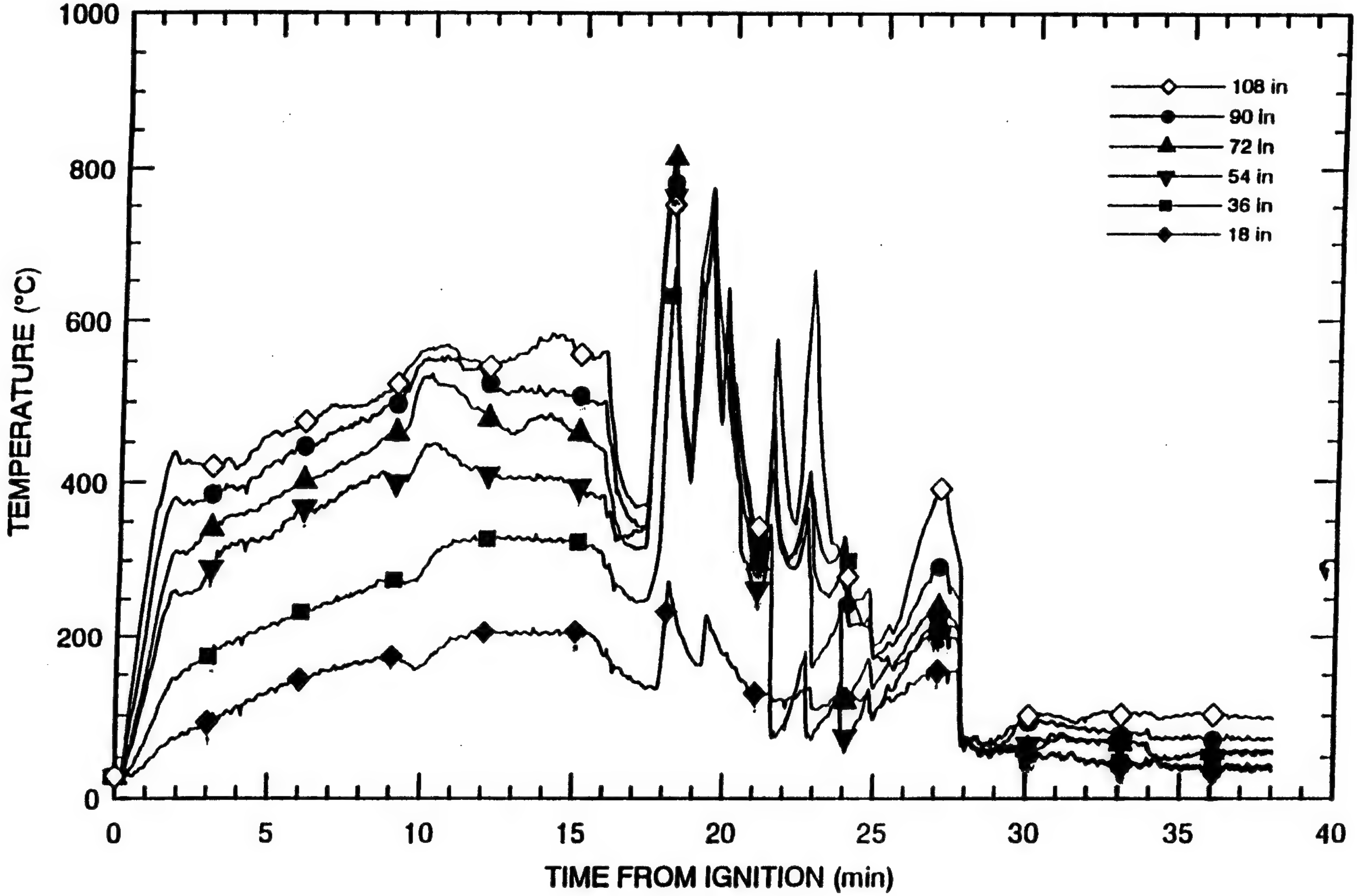


Fig. B14 - Port outer (2-18-2) thermocouple tree for FOG_12

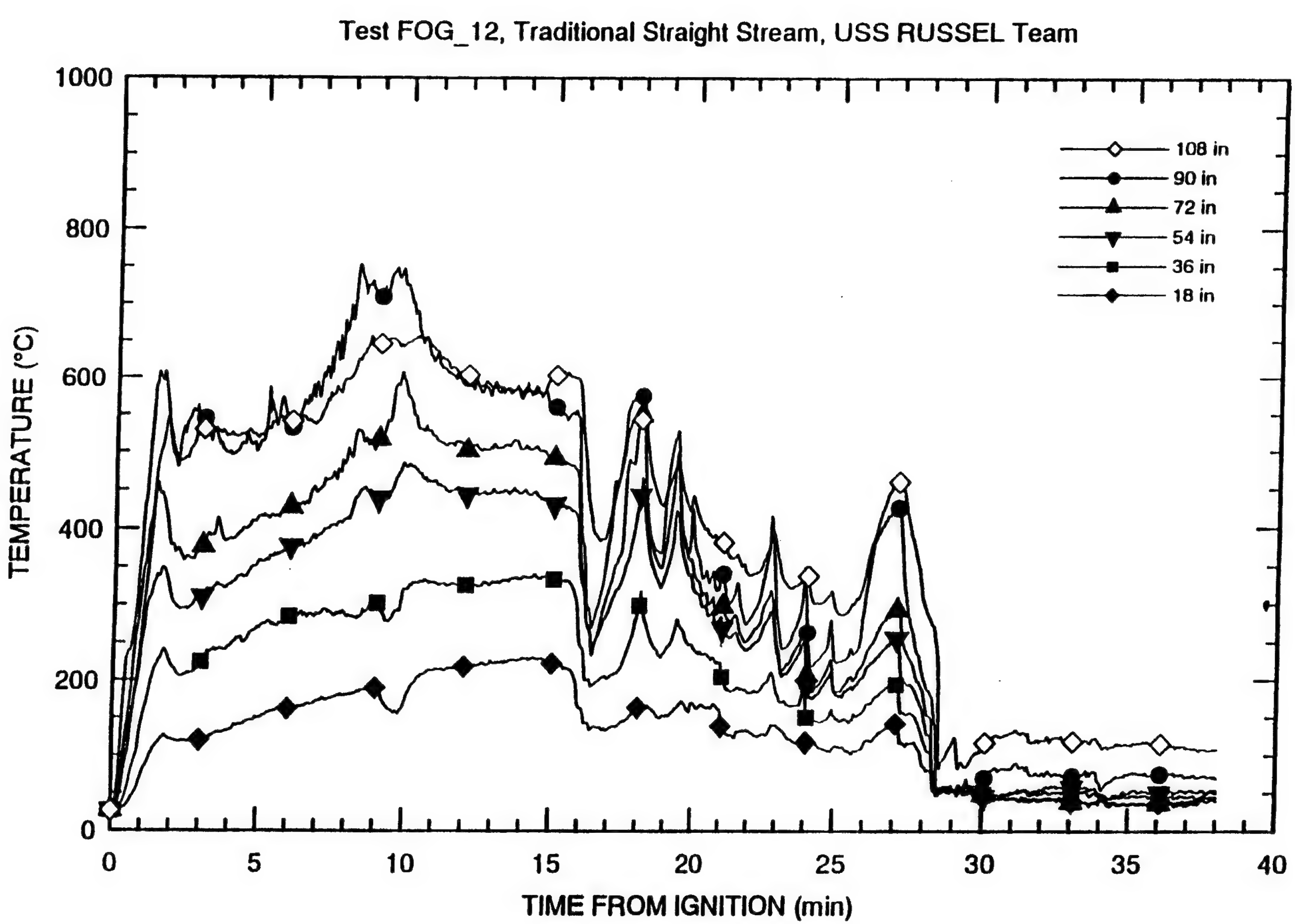


Fig. B15 - Port inner (2-19-0) thermocouple tree for FOG_12

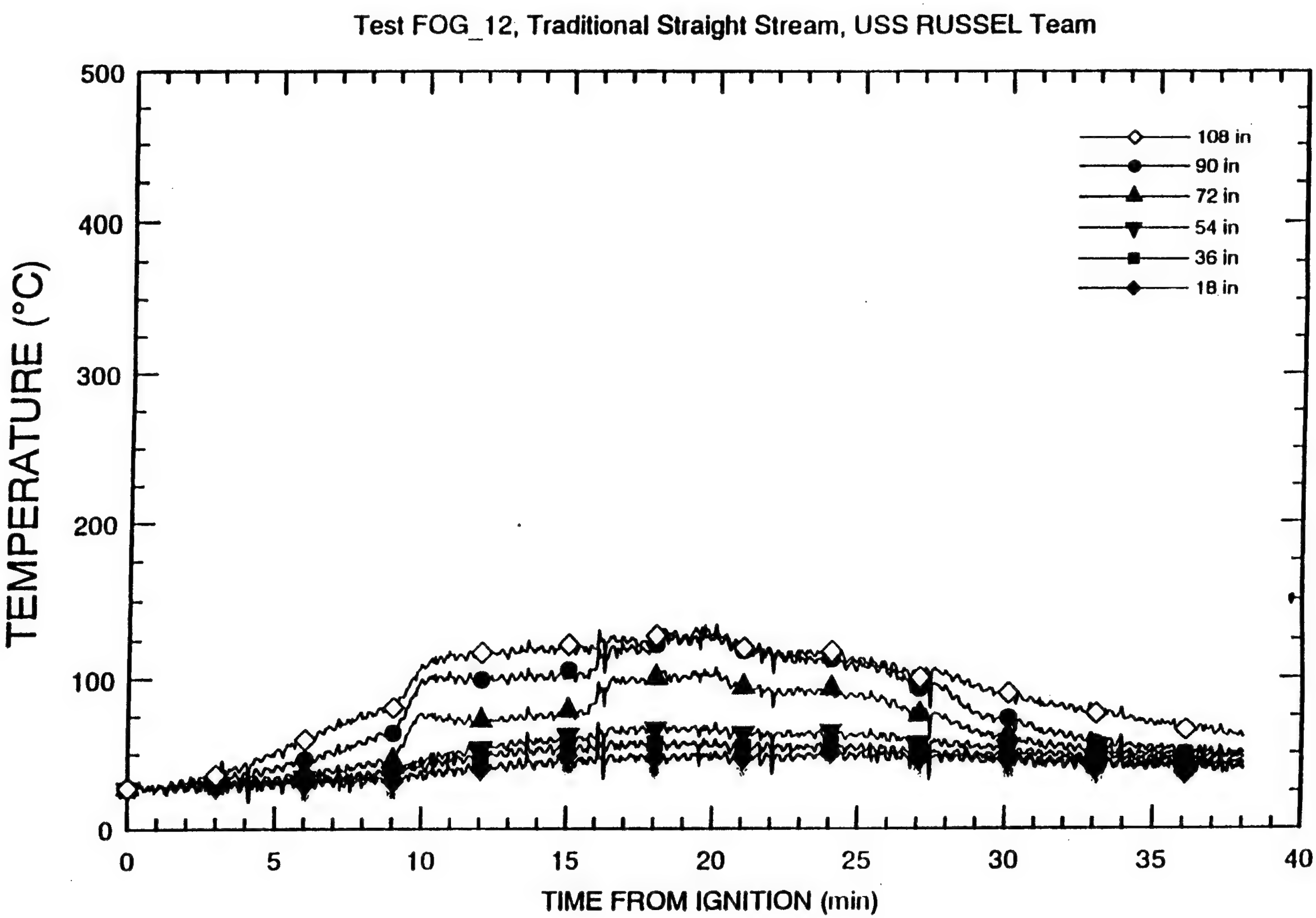


Fig. B16 - Starboard outer (2-21-3) thermocouple tree for FOG_12

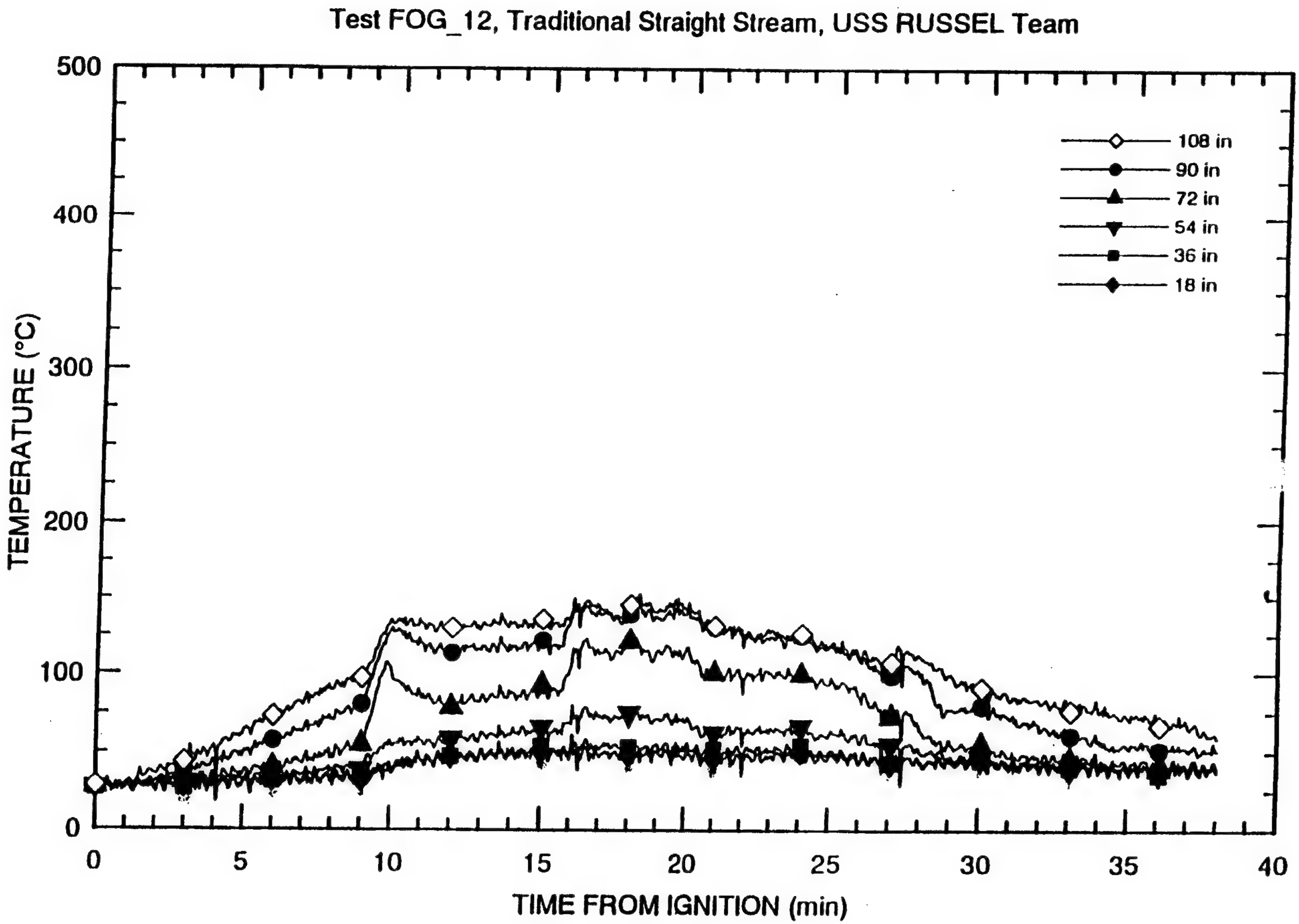


Fig. B17 - Starboard inner (2-21-1) thermocouple tree for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

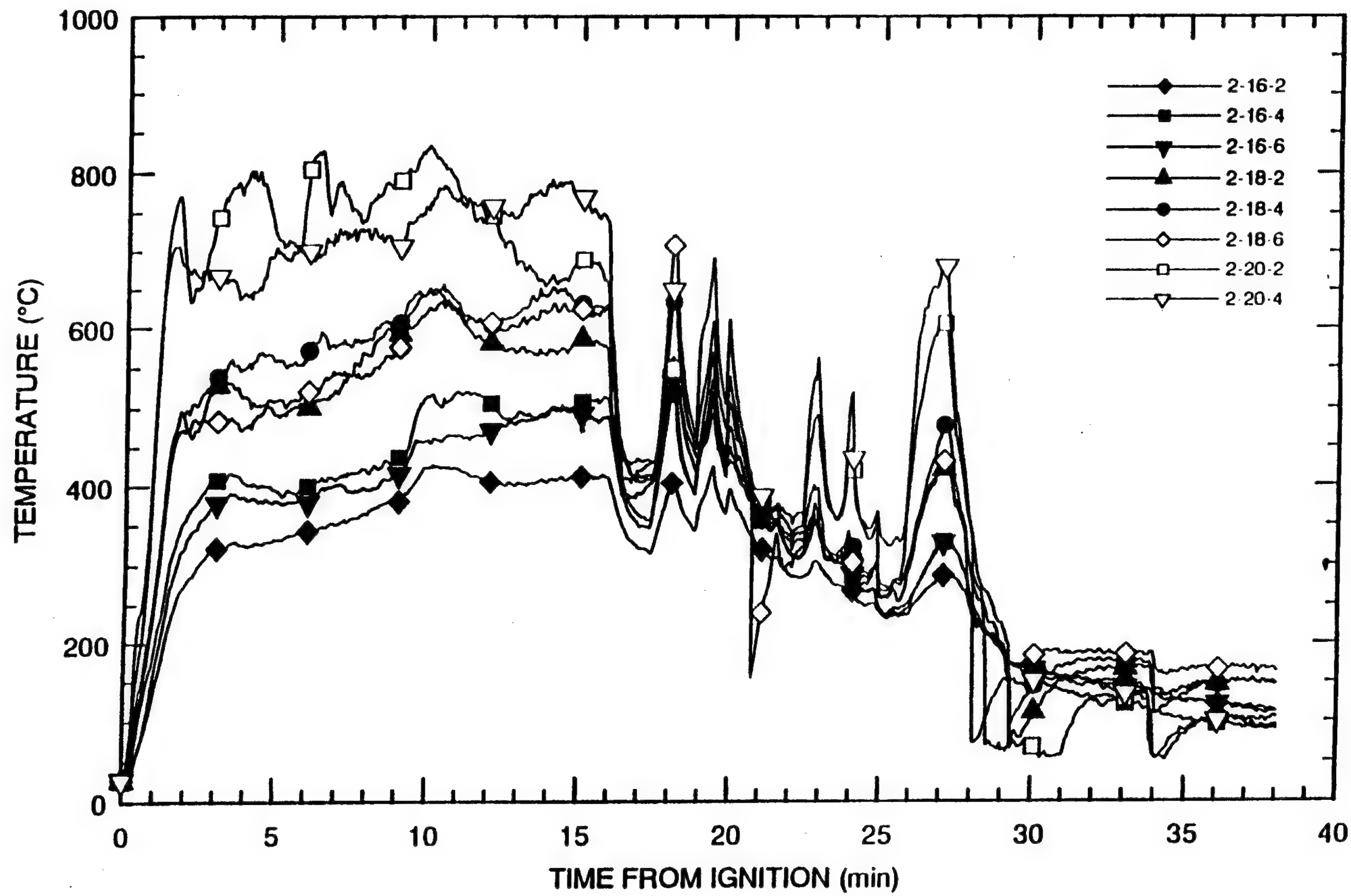


Fig. B18 - Burn room overhead temperatures for FOG_12

Test FOG_12, Traditional Straight Stream, USS RUSSEL Team

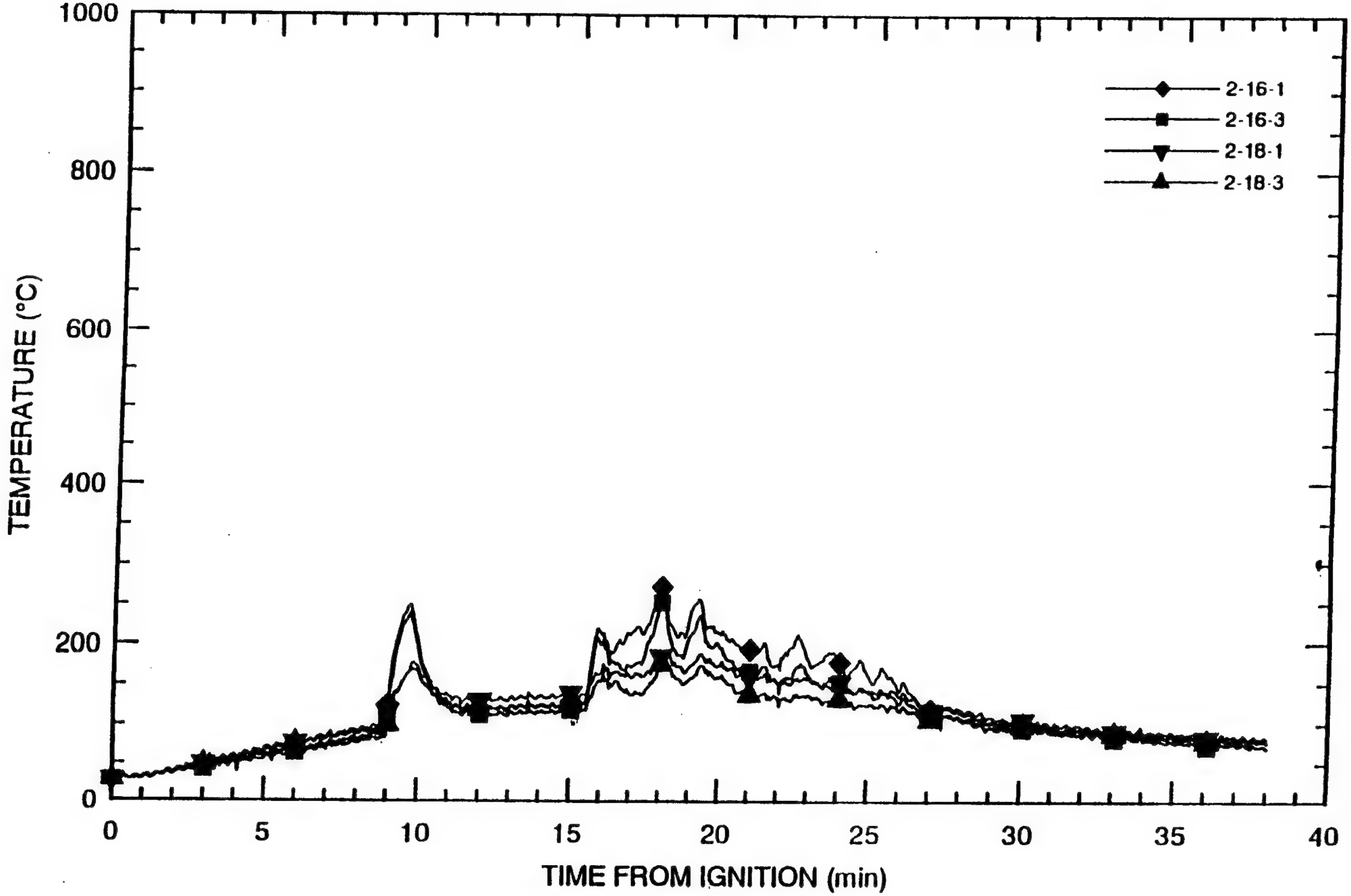


Fig. B19 - GSK overhead temperatures for FOG_12

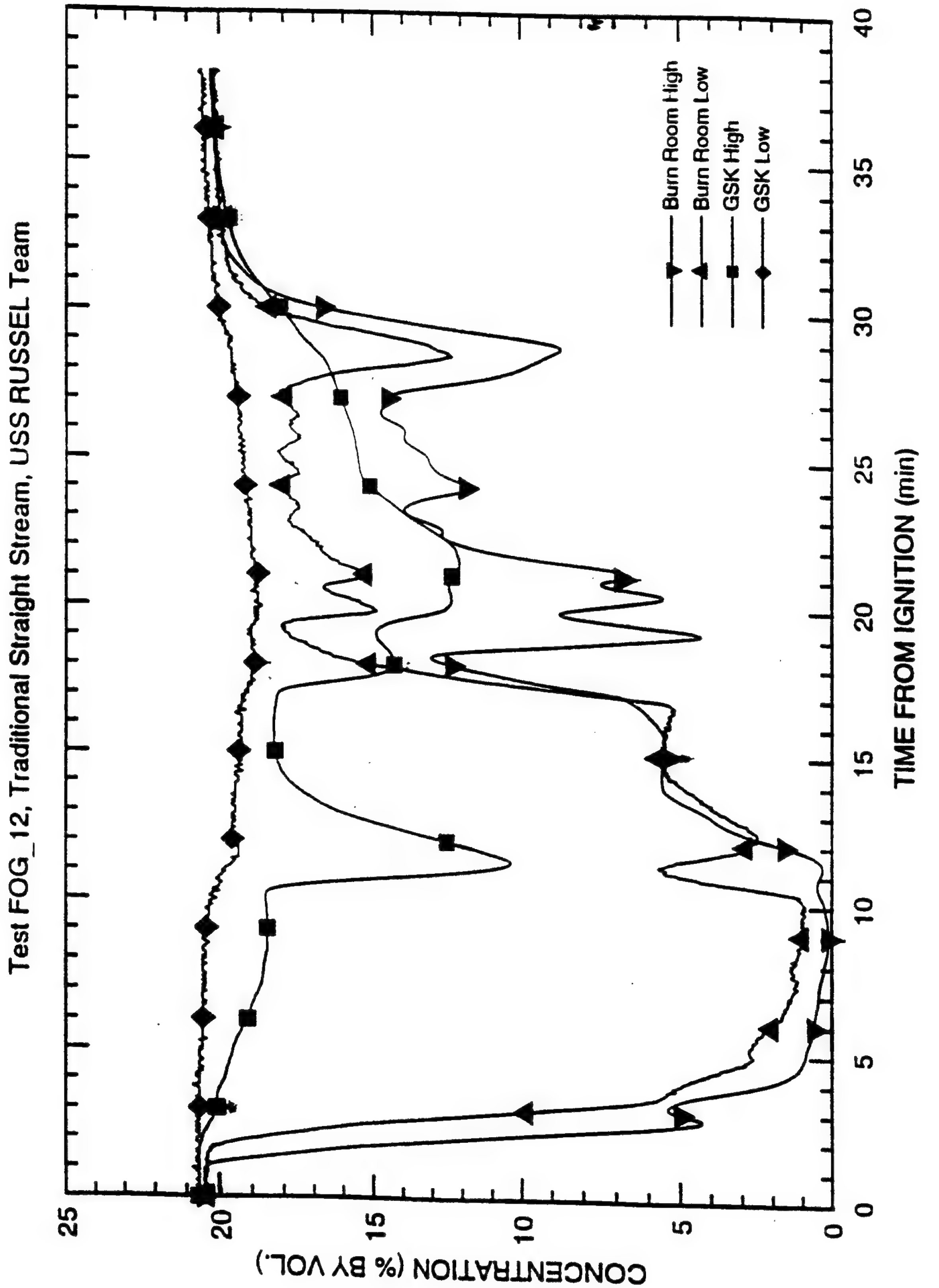


Fig. B20 - Oxygen (O_2) concentrations for FOG_12

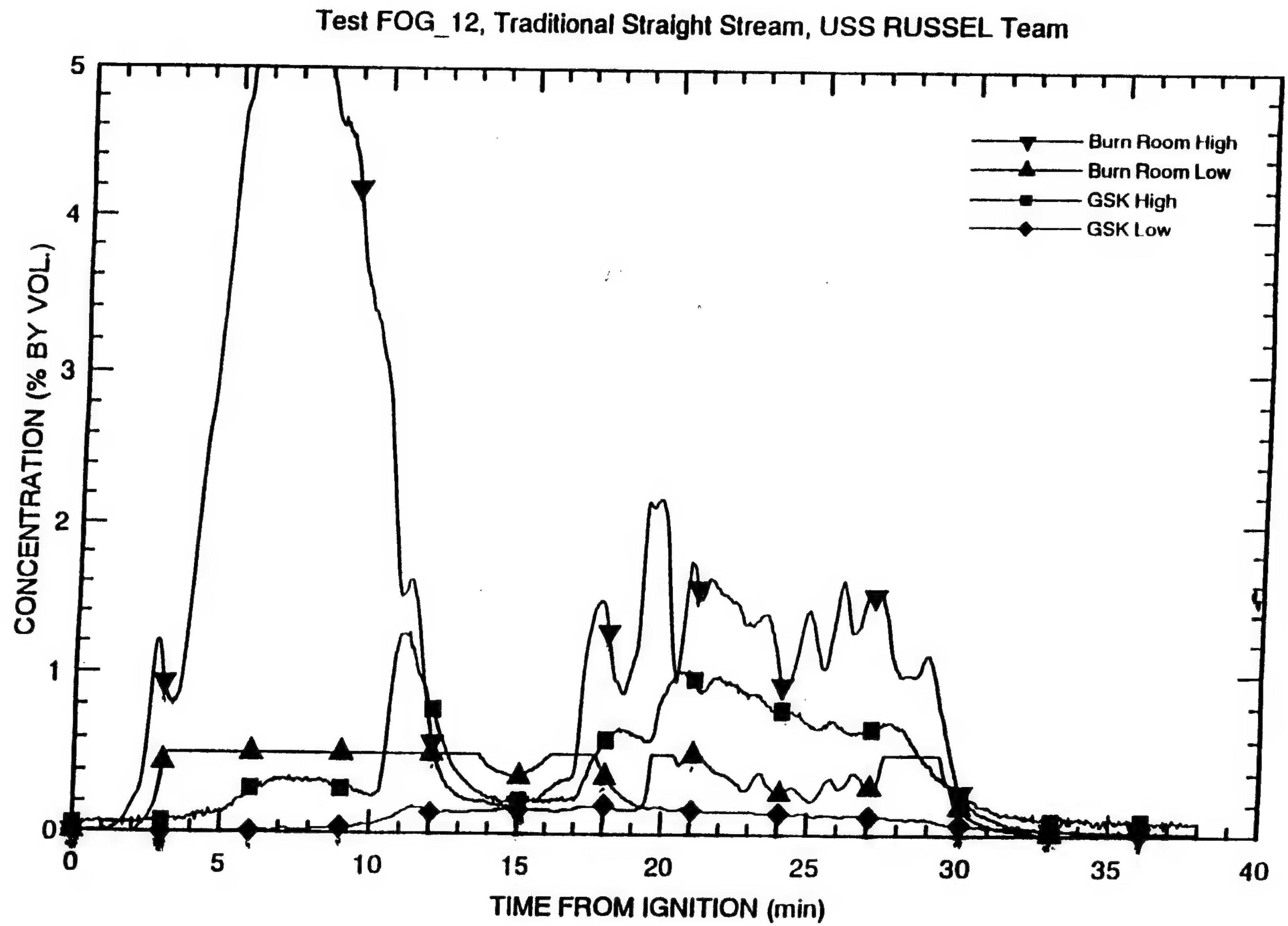


Fig. B21 - Carbon monoxide (CO) concentrations for FOG_12

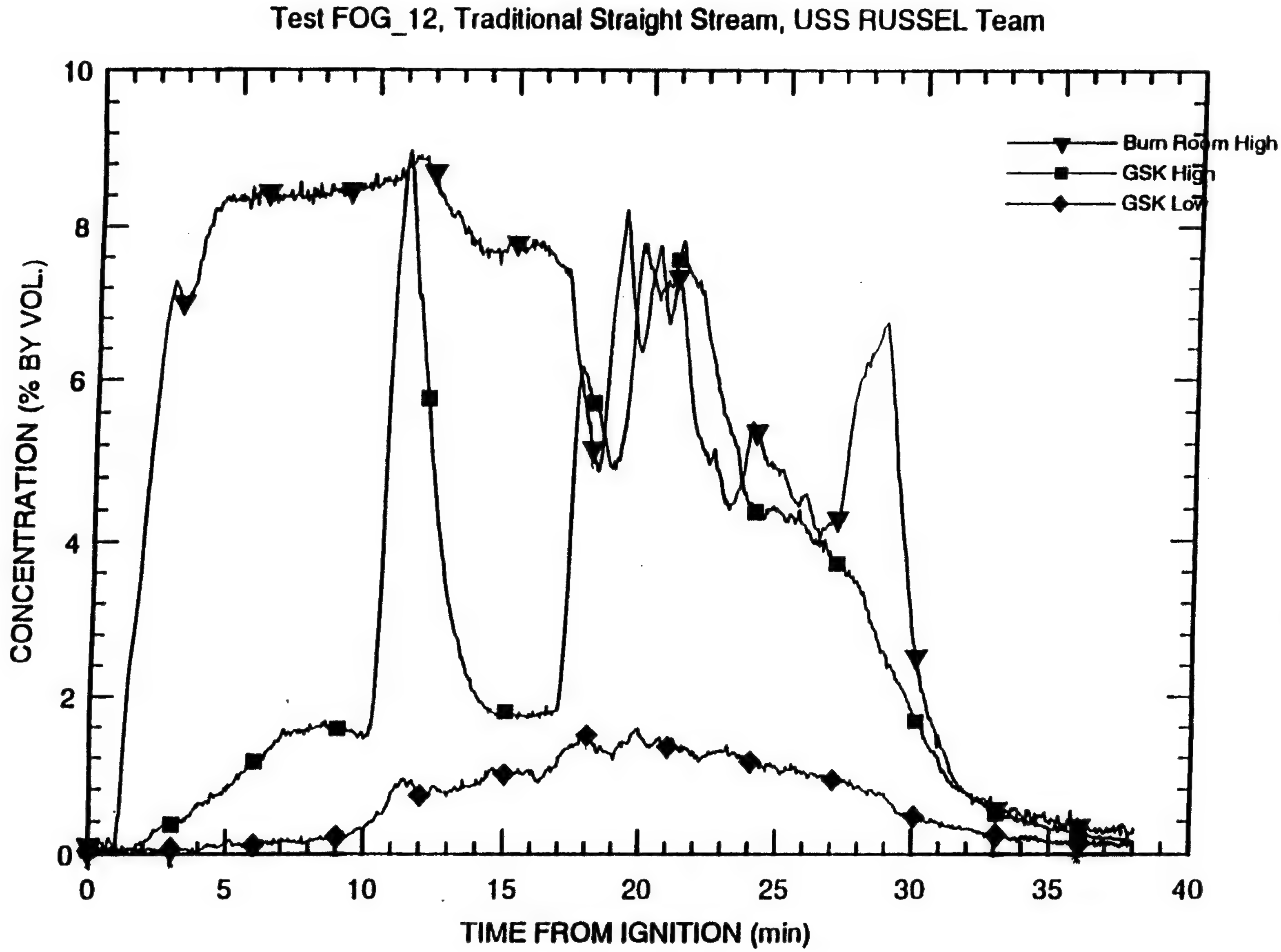


Fig. B22 - Carbon dioxide (CO_2) concentrations for FOG_12

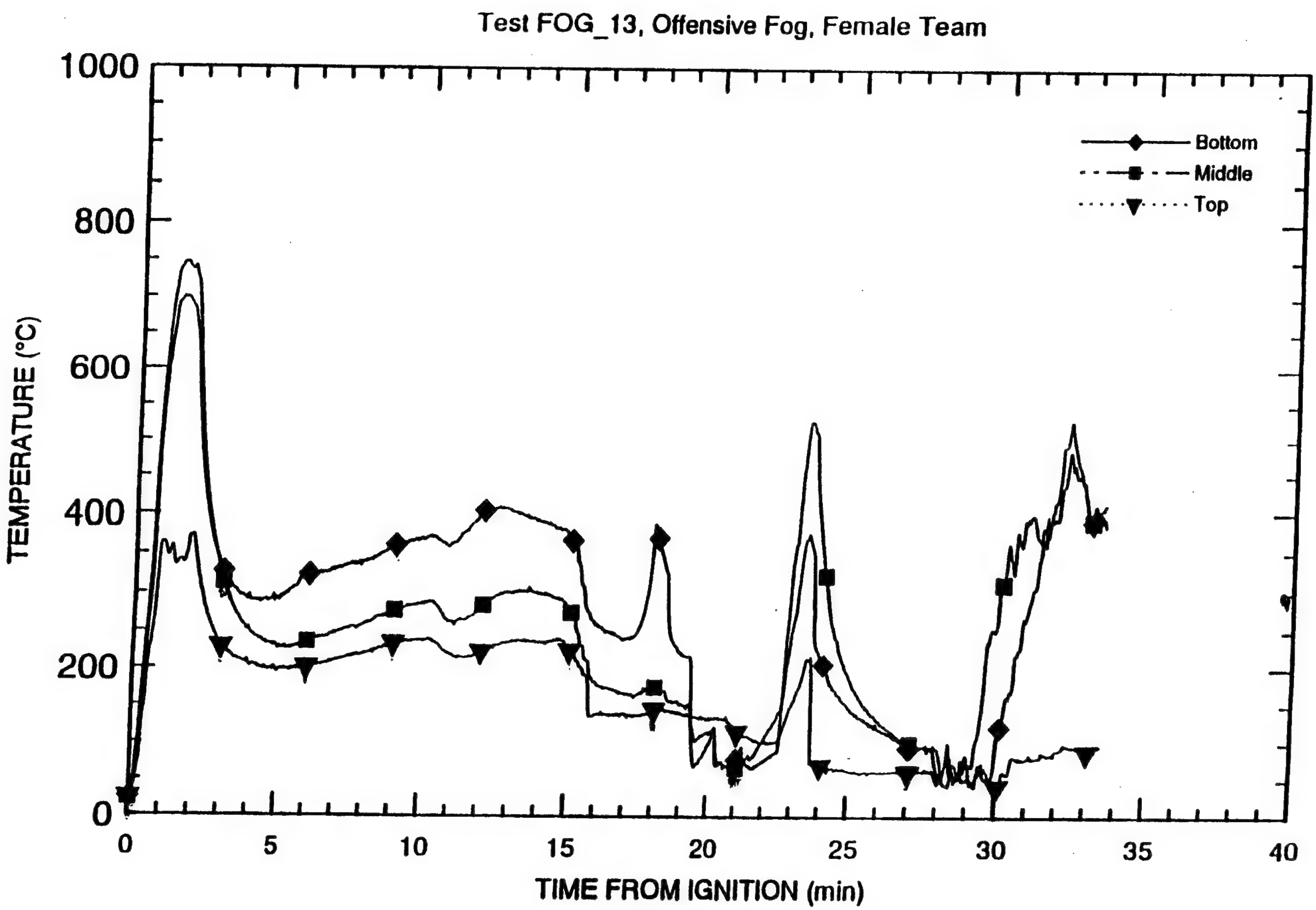


Fig. B23 - Wood crib #1 thermocouples for FOG_13

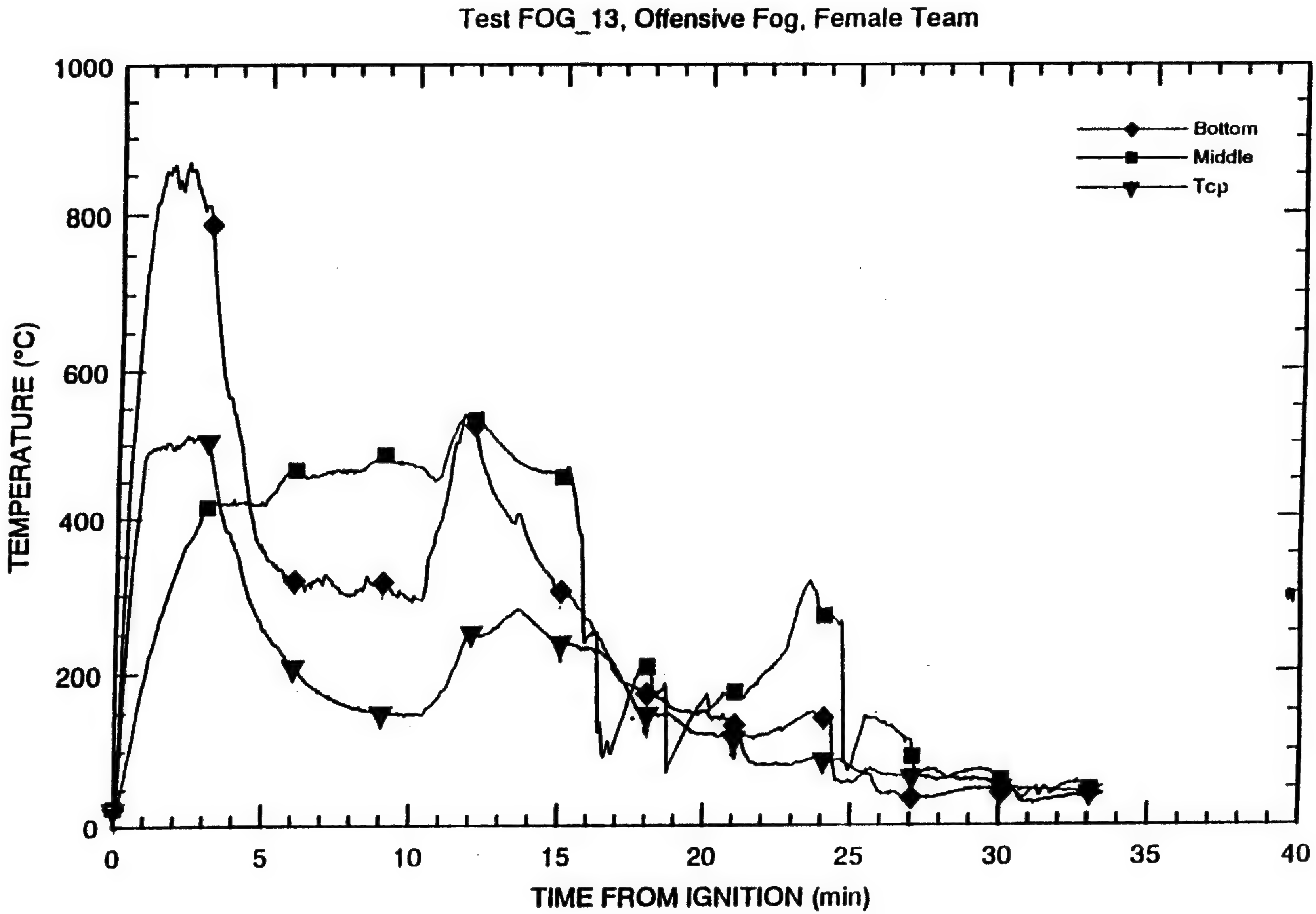


Fig. B24 - Wood crib #2 thermocouples for FOG_13

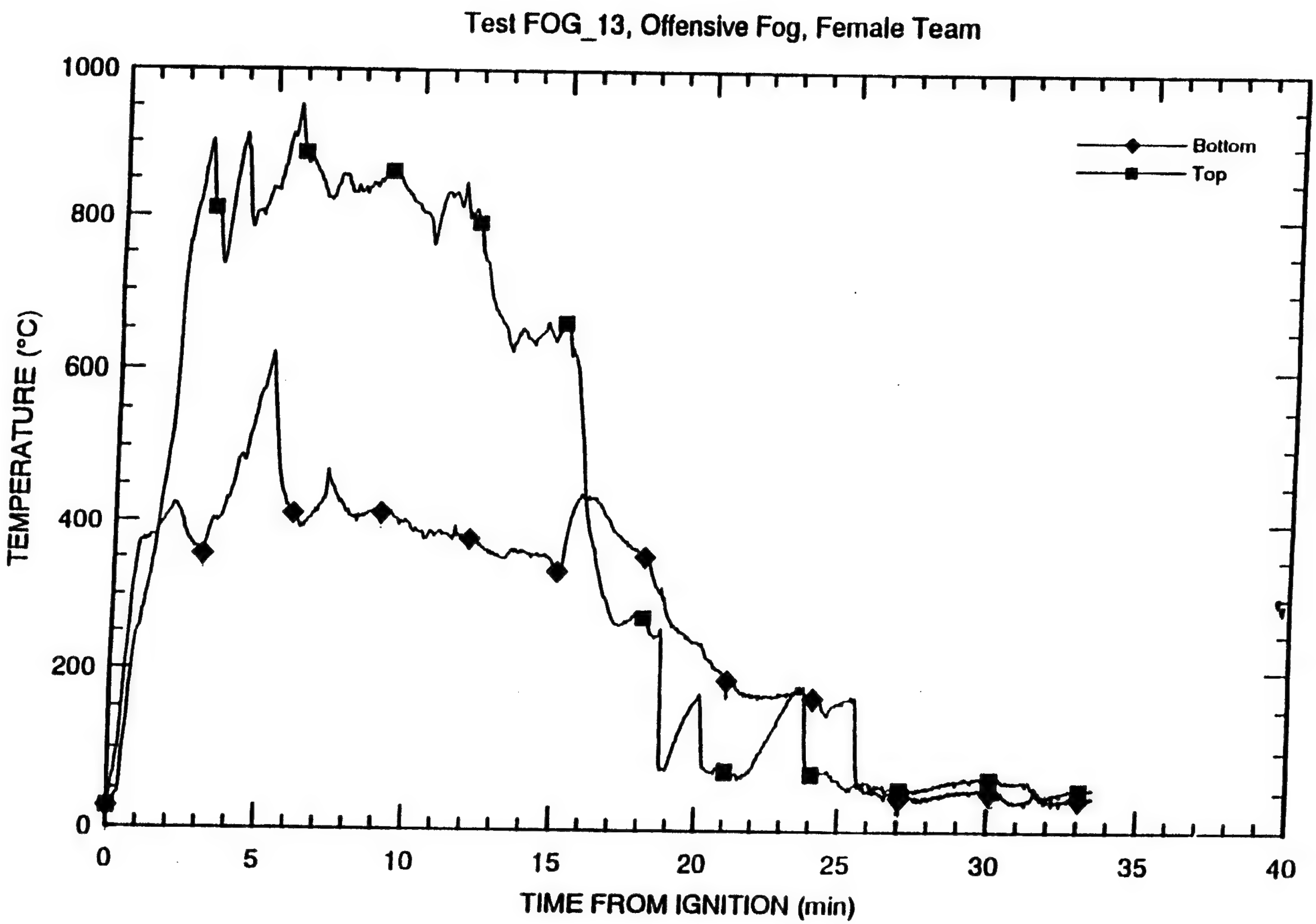


Fig. B25 - Wood crib #3 thermocouples for FOG_13

Test FOG_13, Offensive Fog, Female Team

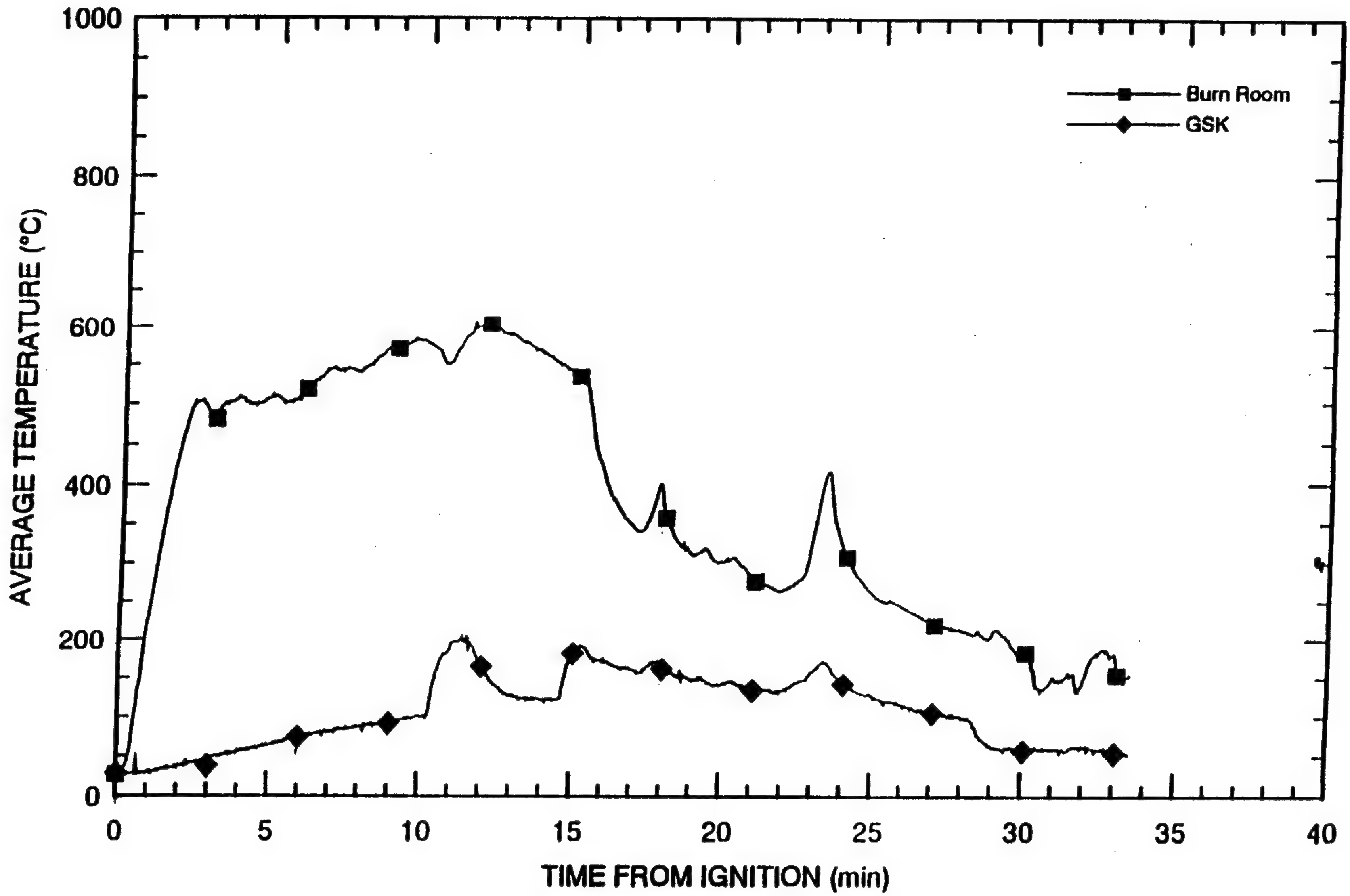


Fig. B26 - Average of overhead thermocouples for FOG_13

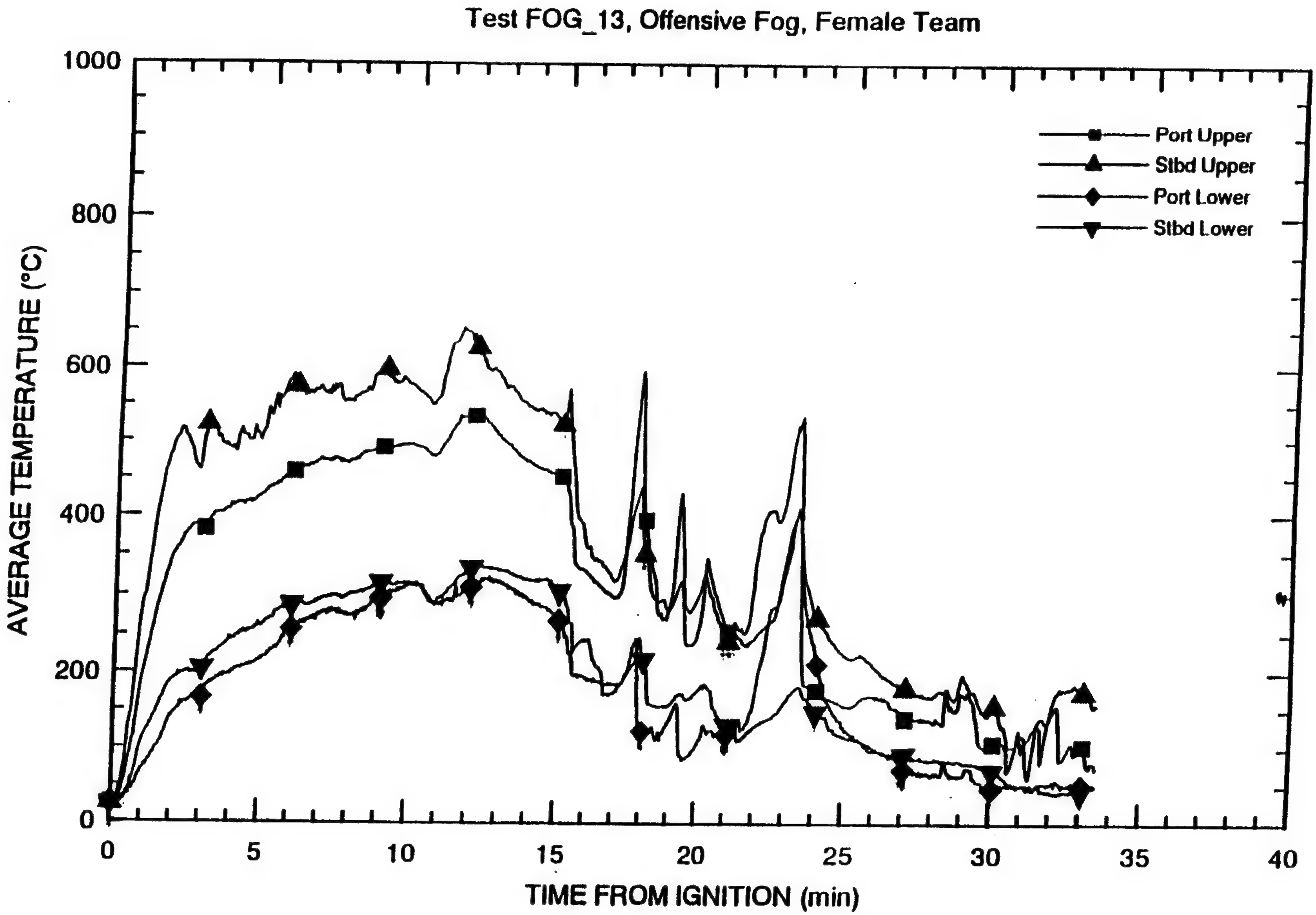


Fig. B27 - Burn room thermocouple string averages (upper vs. lower) for FOG_13

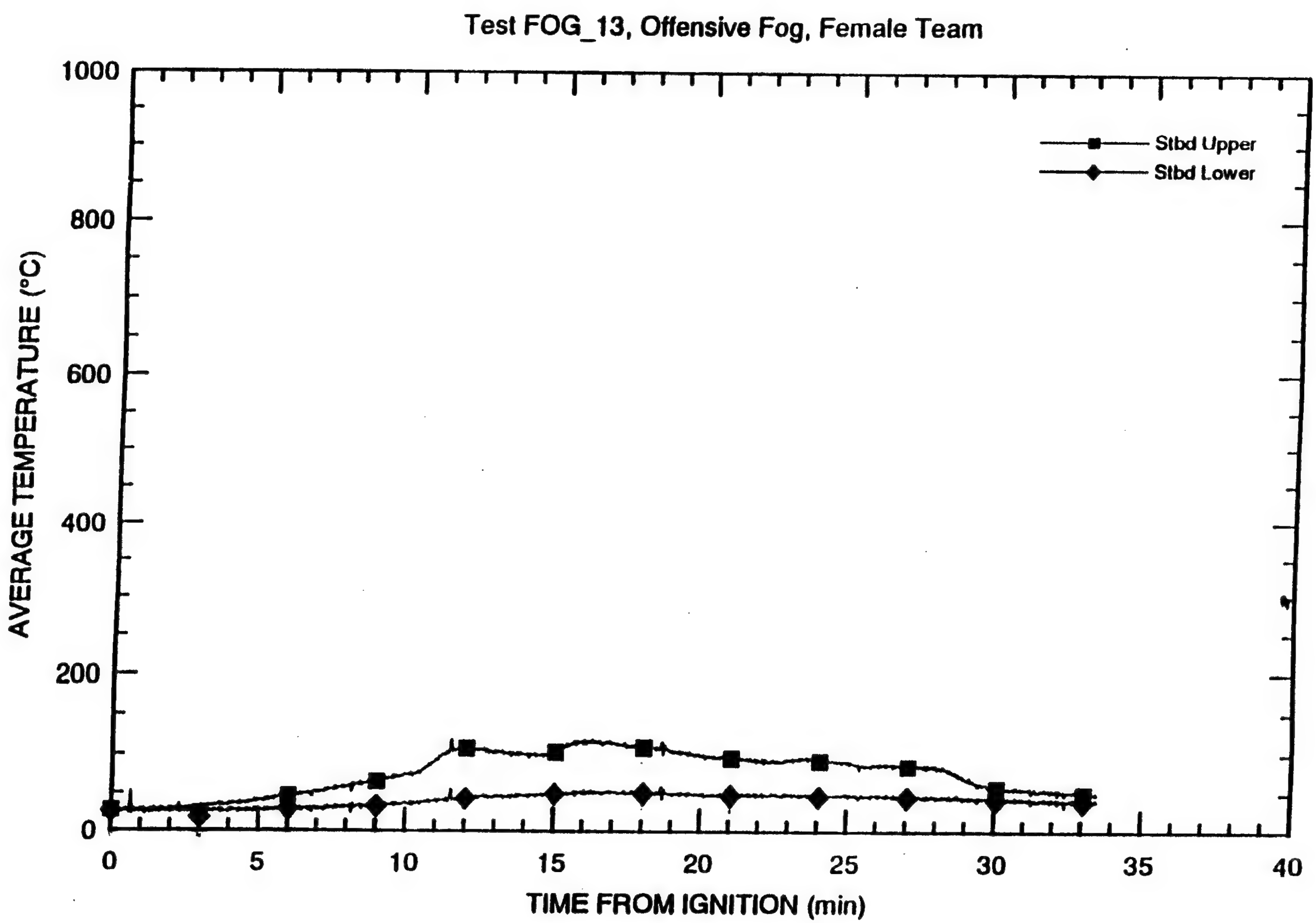


Fig. B28 - GSK thermocouple string averages (upper vs. lower) for FOG_13

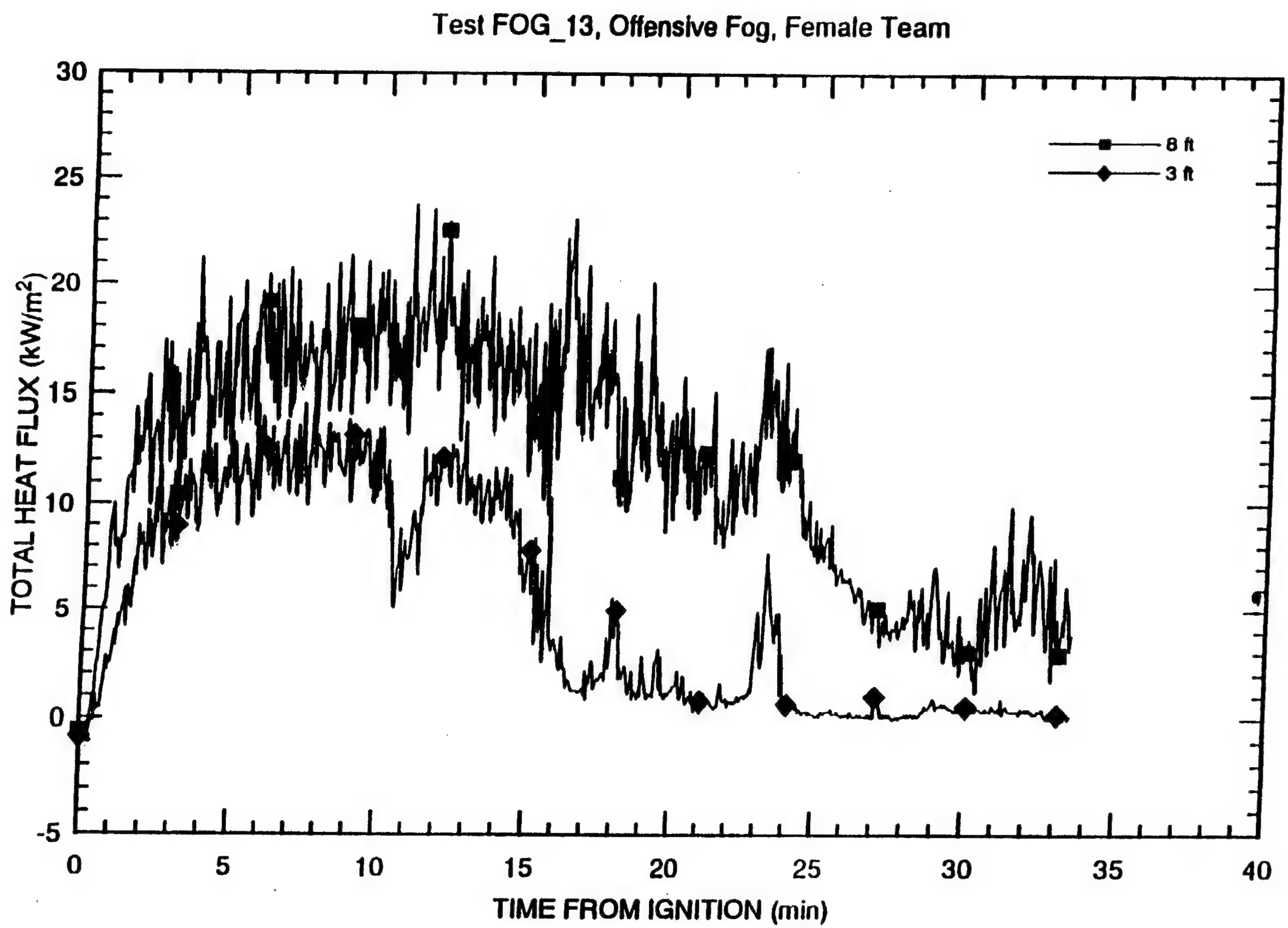


Fig. B29 - Burn room calorimeters for FOG_13

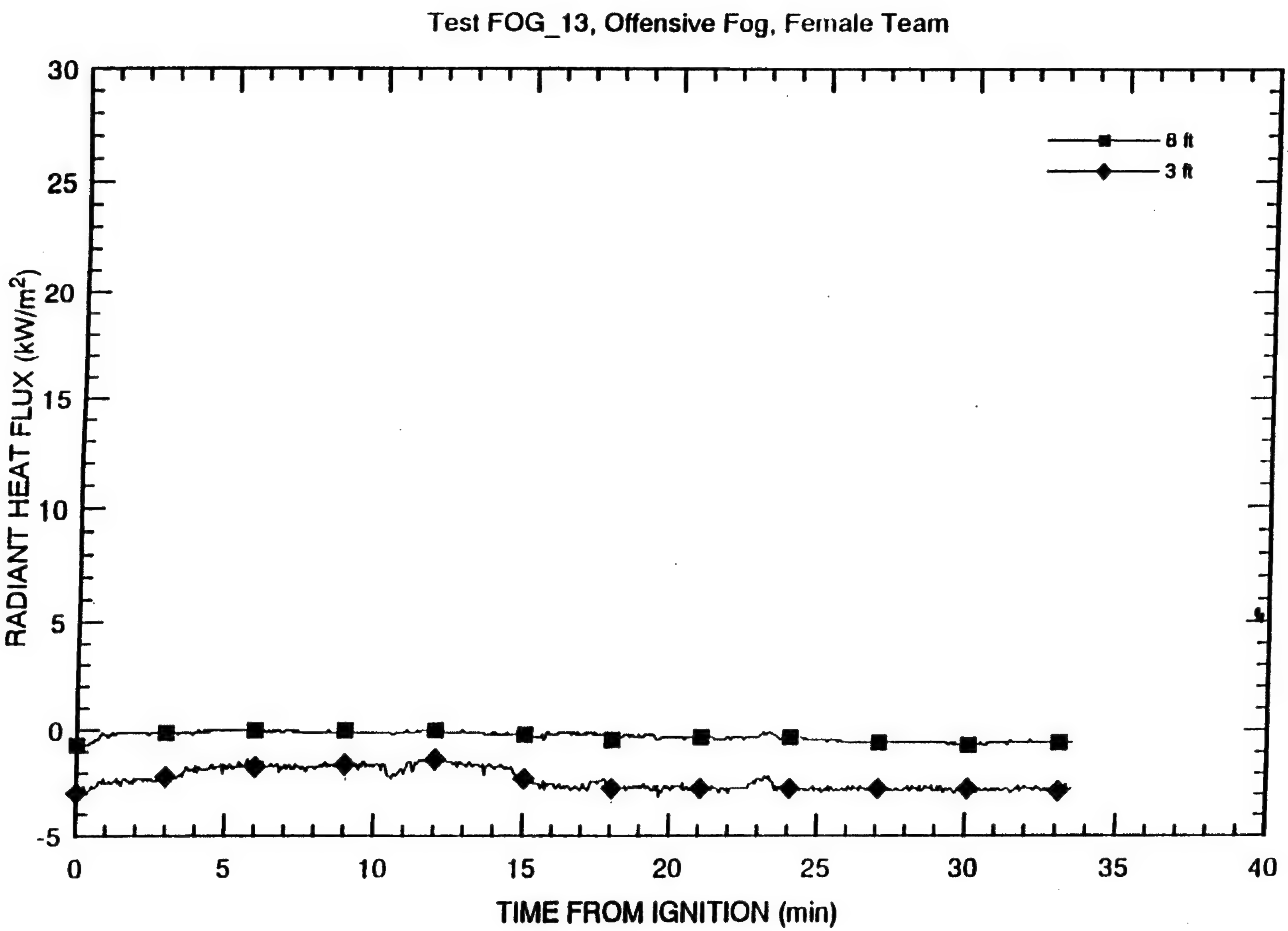


Fig. B30 - Burn room radiometers for FOG_13

Test FOG_13, Offensive Fog, Female Team

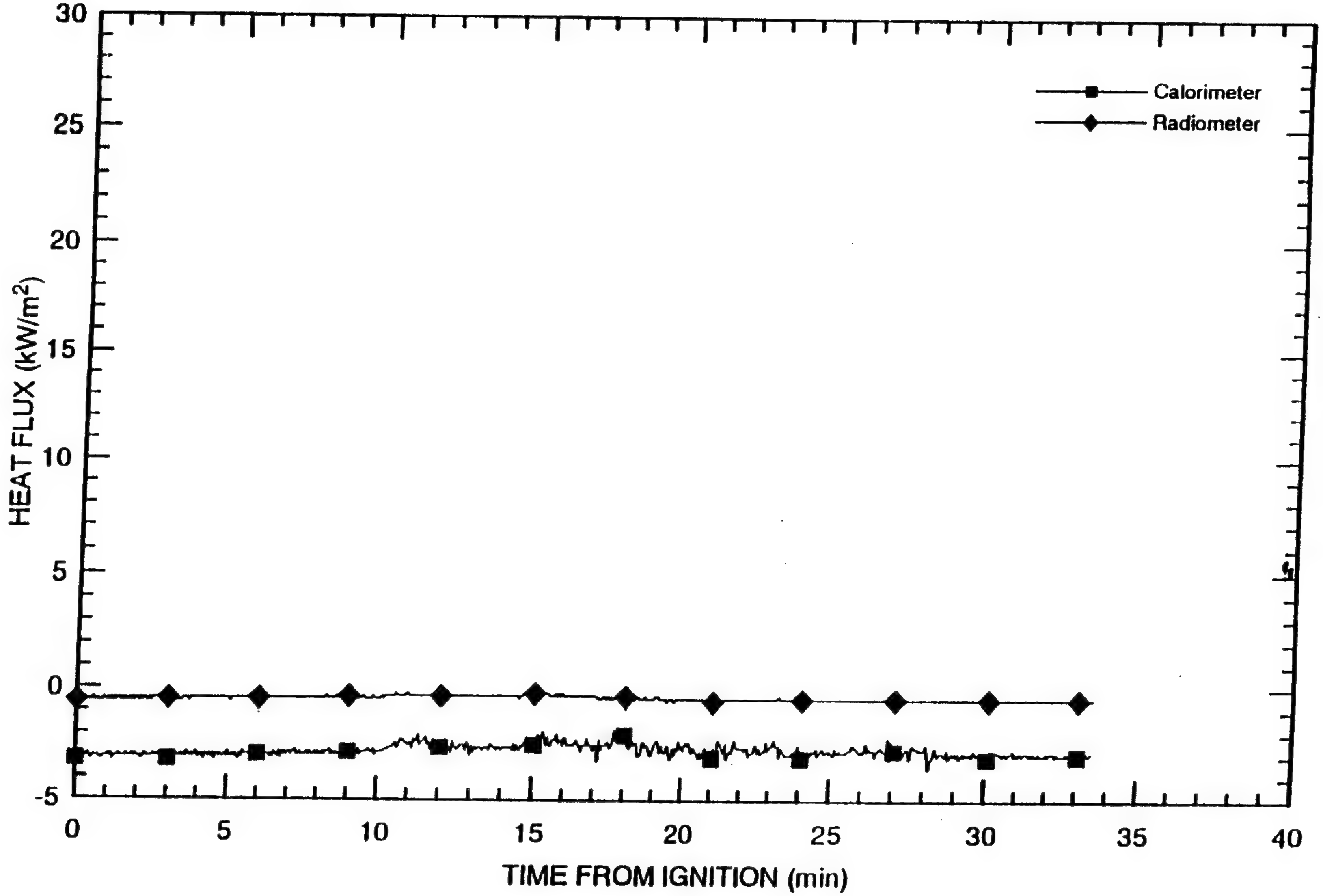


Fig. B31 - GSK radiometer and calorimeter for FOG_13

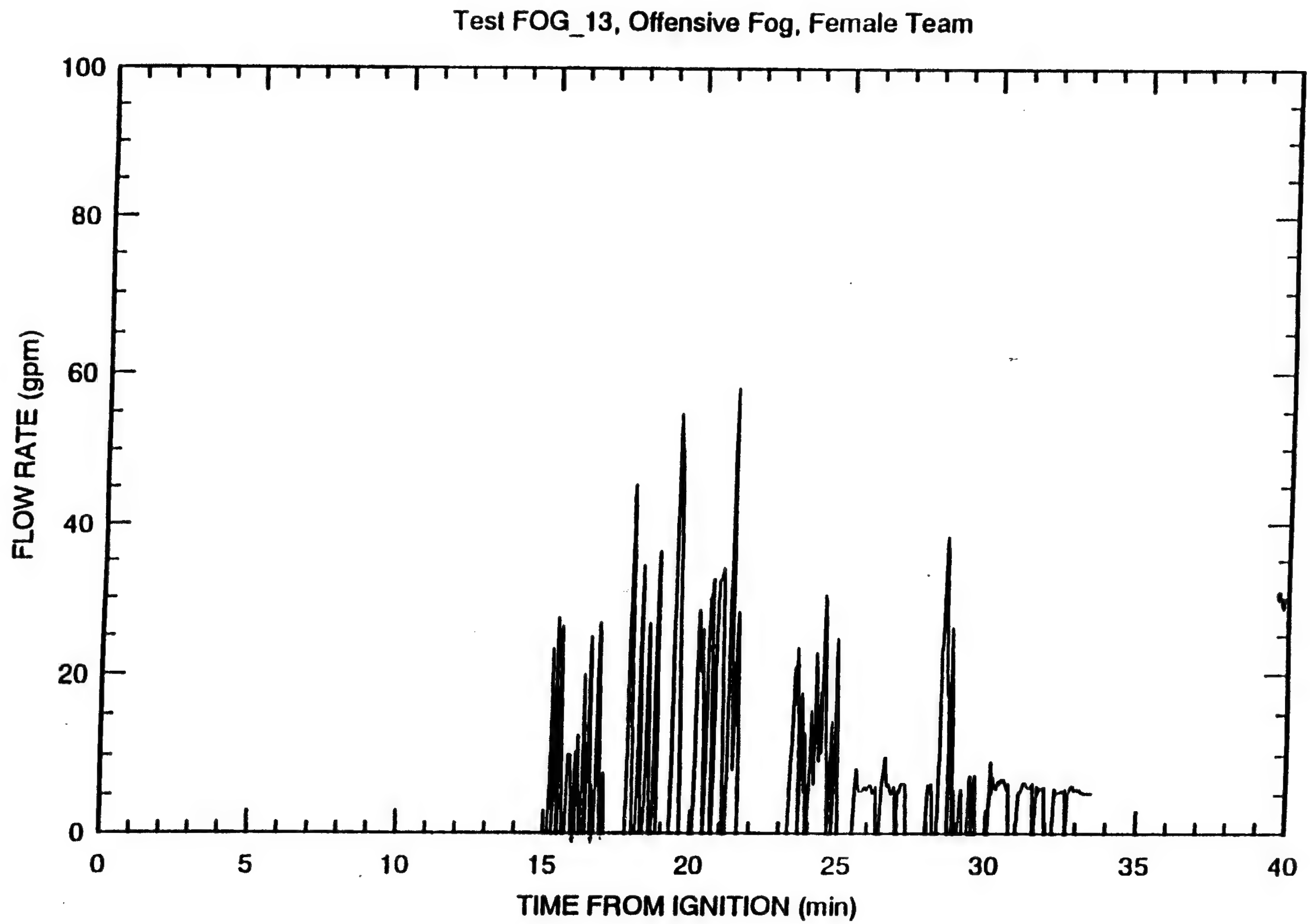


Fig. B32 - Water flow rate for FOG_13

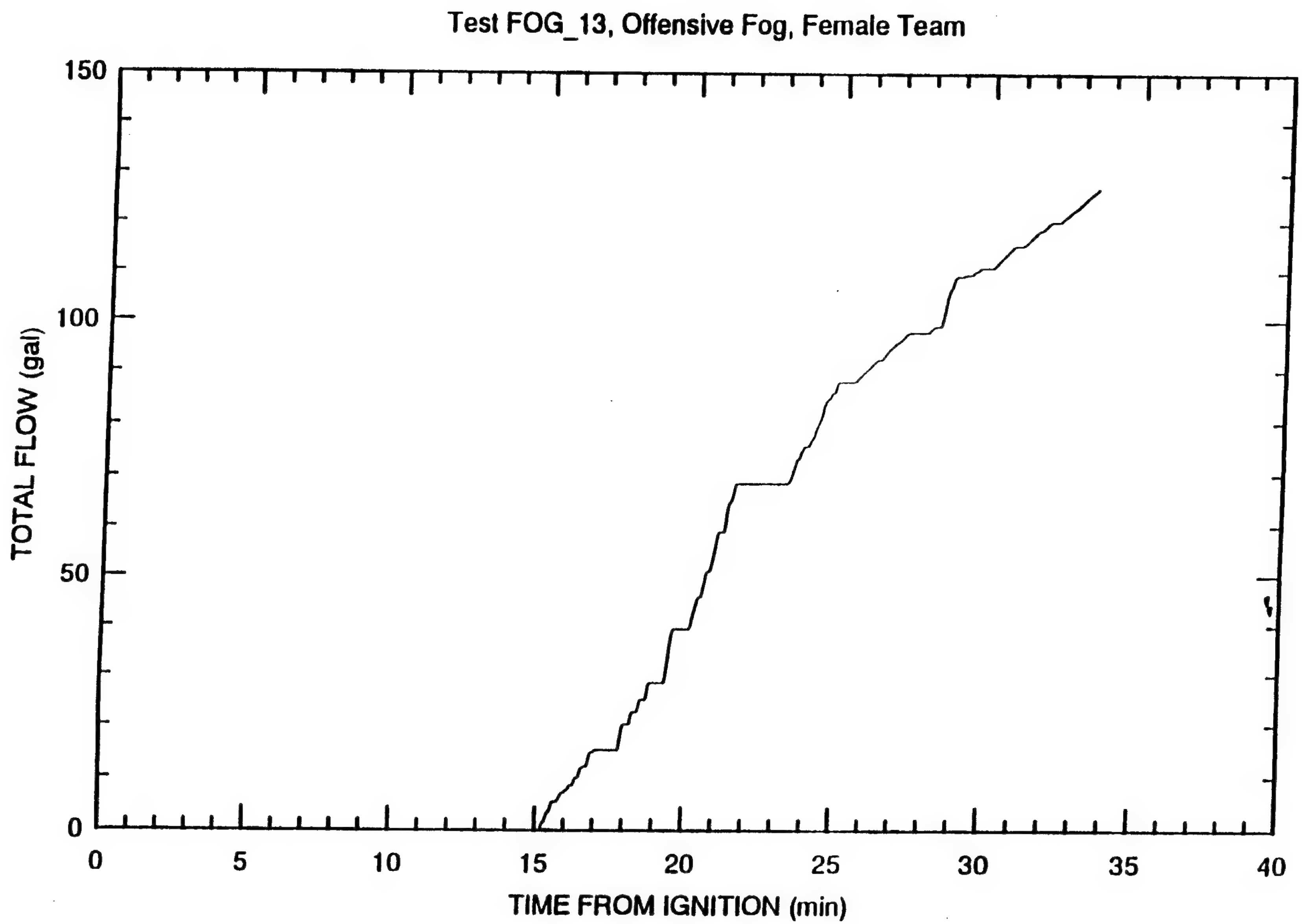


Fig. B33 - Cumulative water flow for FOG_13

Test FOG_13, Offensive Fog, Female Team

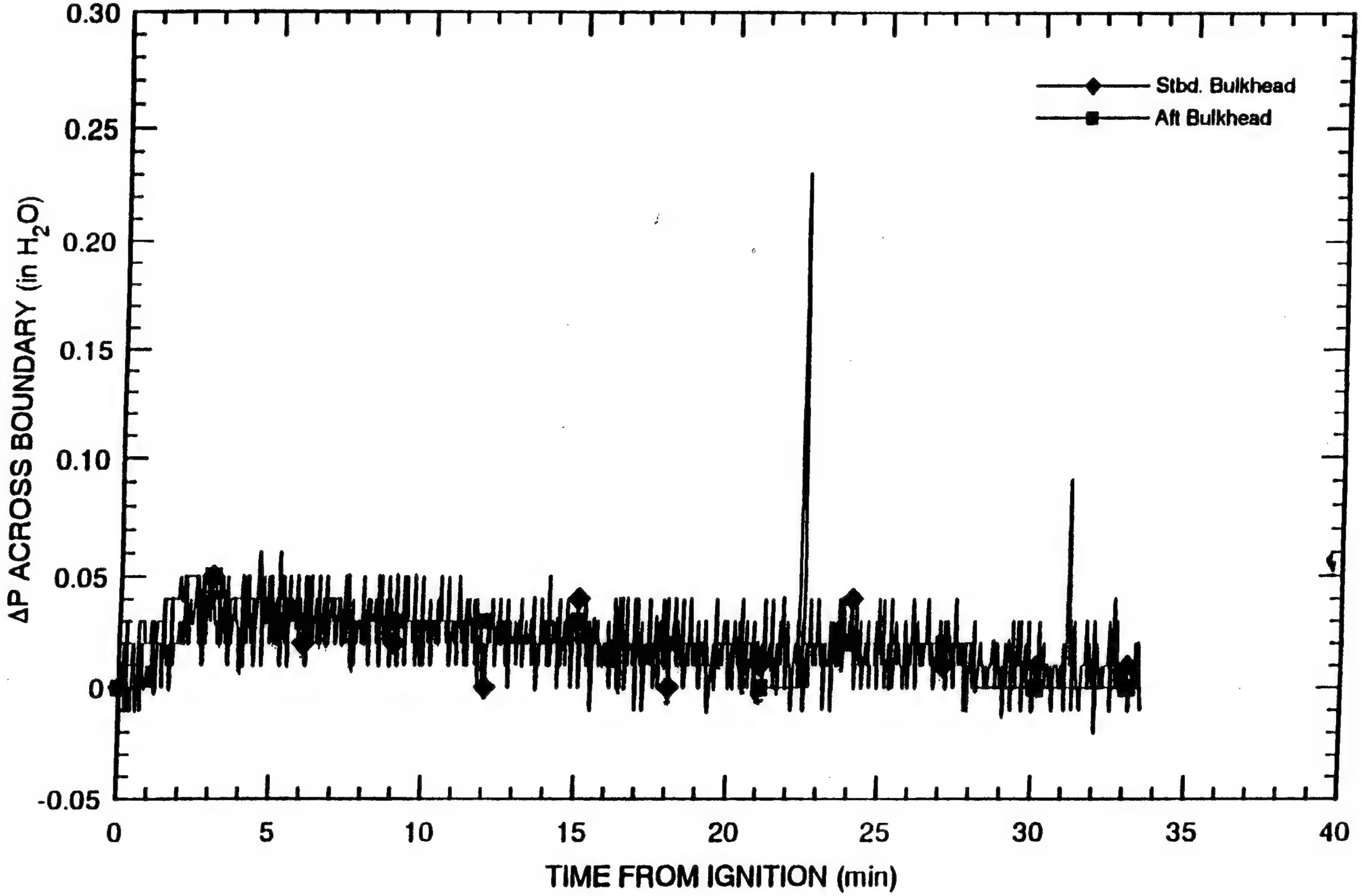


Fig. B34 - Pressure differential across burn room boundaries for FOG_13

Test FOG_13, Offensive Fog, Female Team

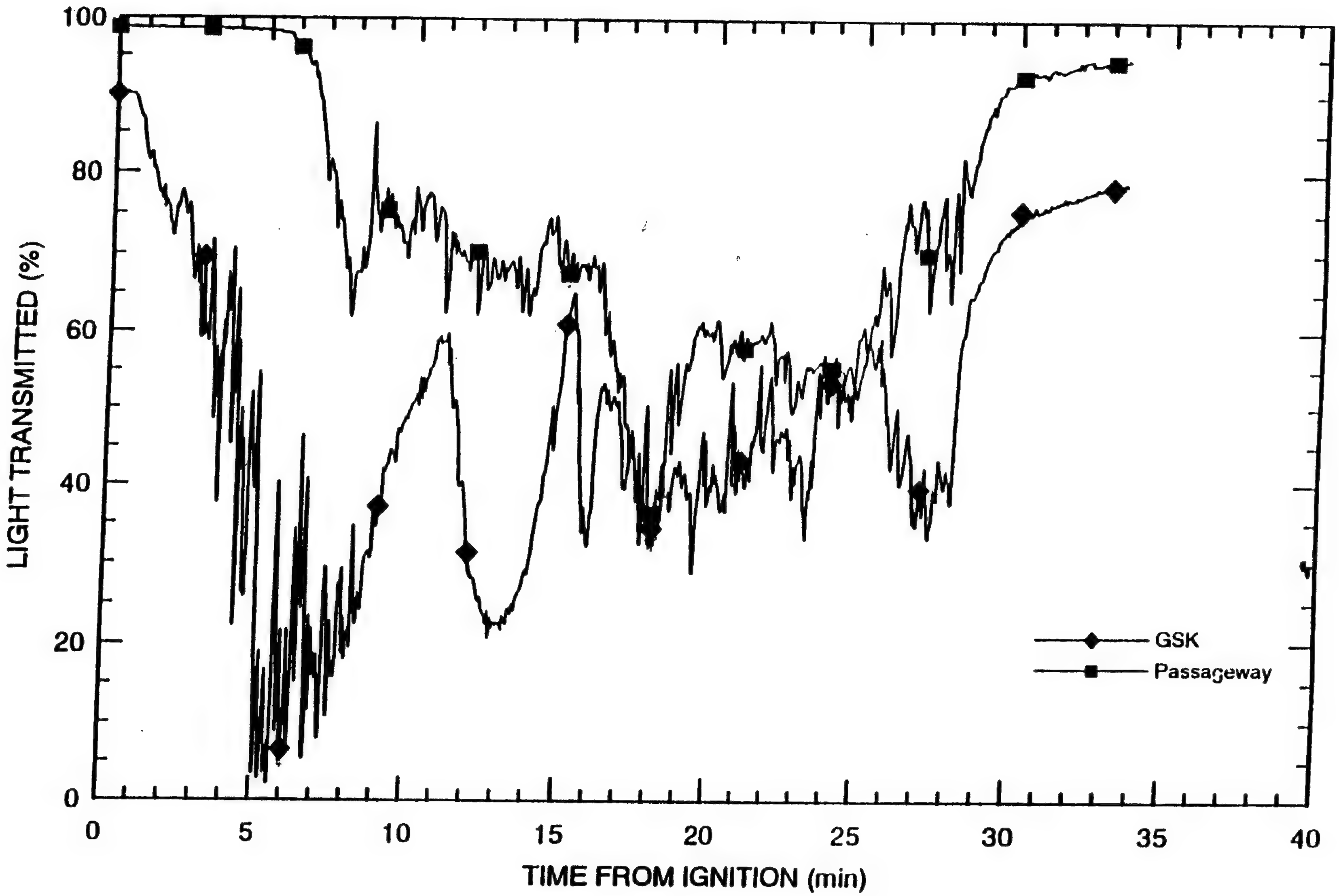


Fig. B35 - Smoke Obscuration for FOG_13

Test FOG_13, Offensive Fog, Female Team

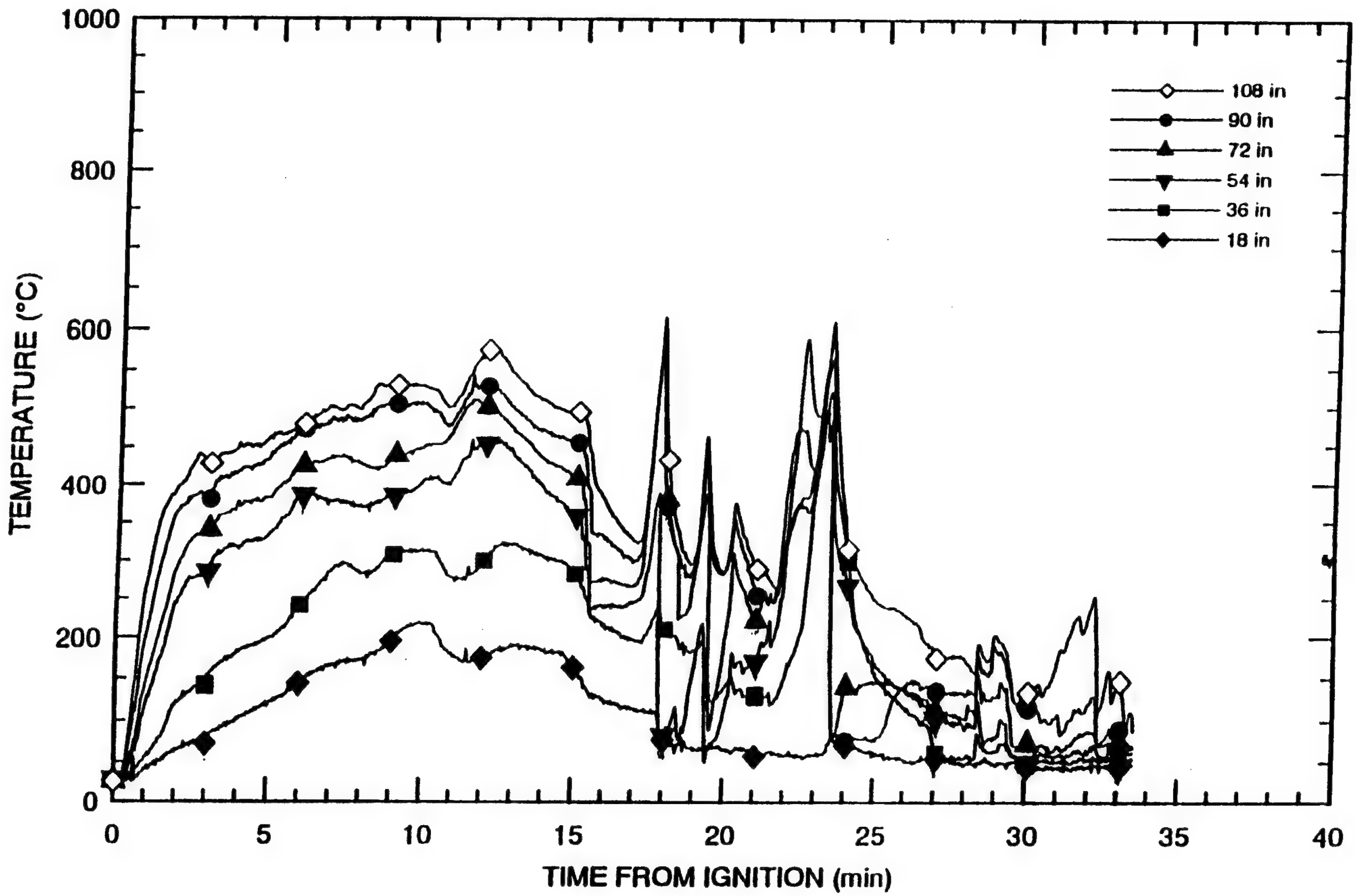


Fig. B36 - Port outer (2-18-2) thermocouple tree for FOG_13

Test FOG_13, Offensive Fog, Female Team

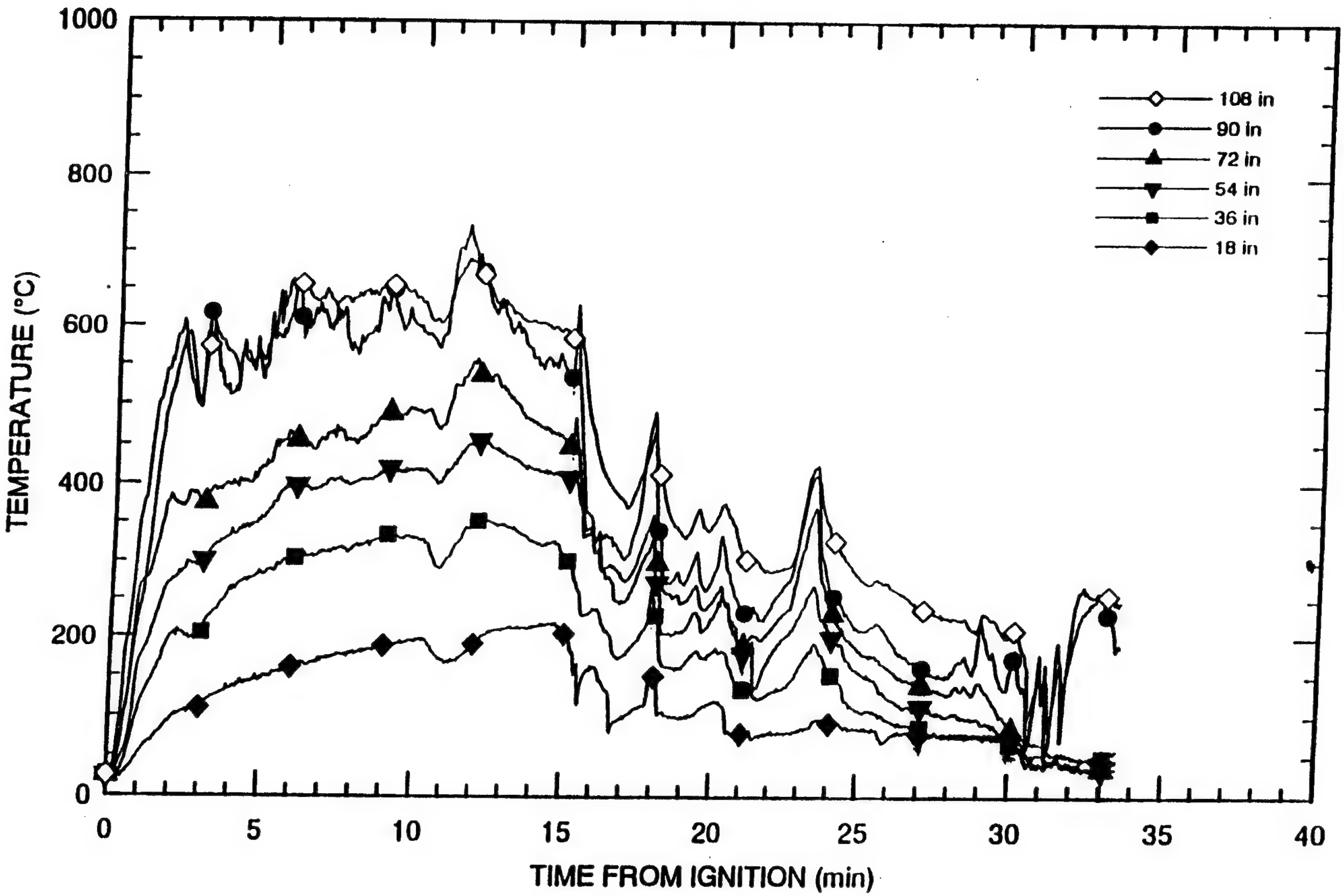


Fig. B37 - Port inner (2-19-0) thermocouple tree for FOG_13

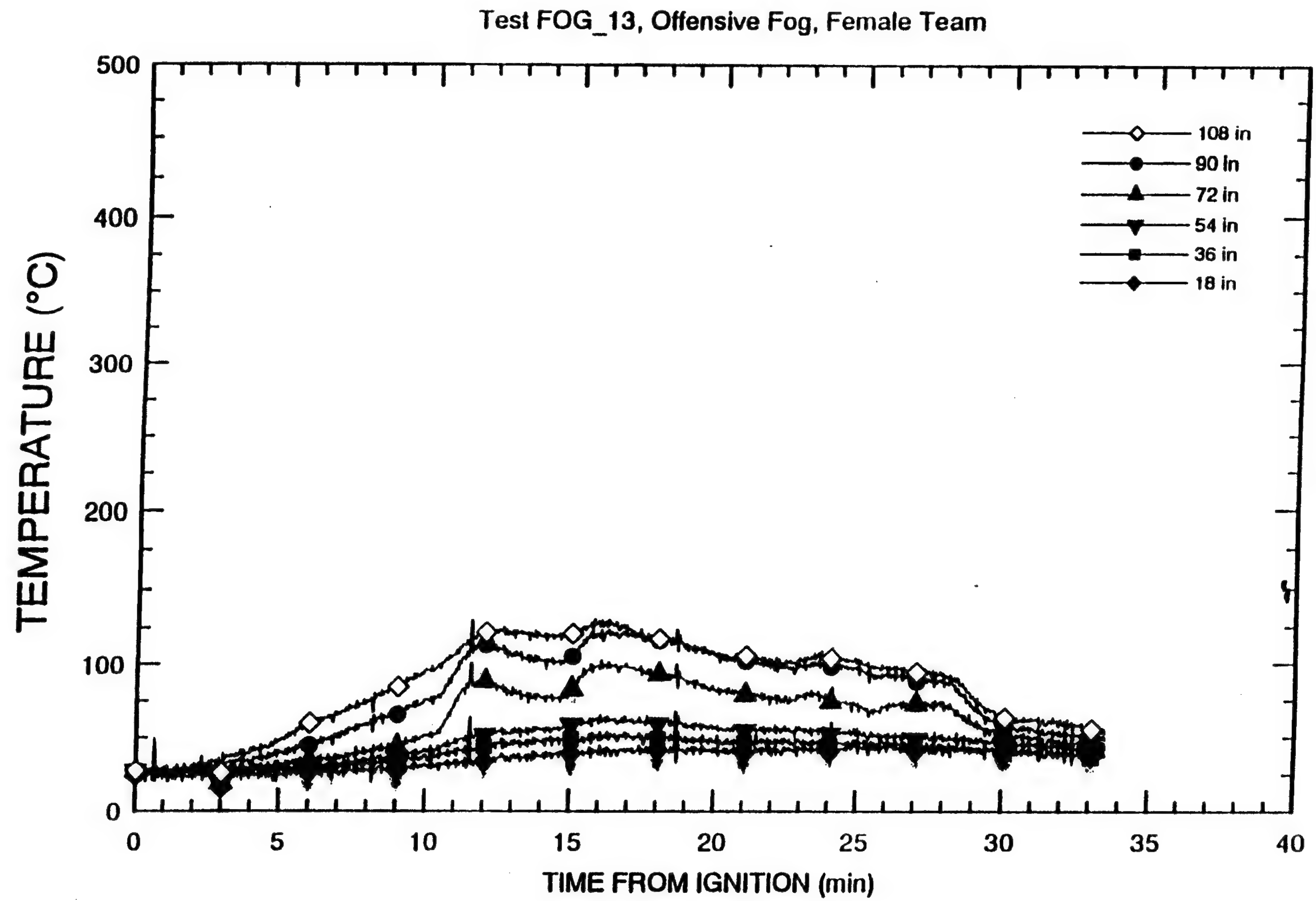


Fig. B38 - Starboard outer (2-21-3) thermocouple tree for FOG_13

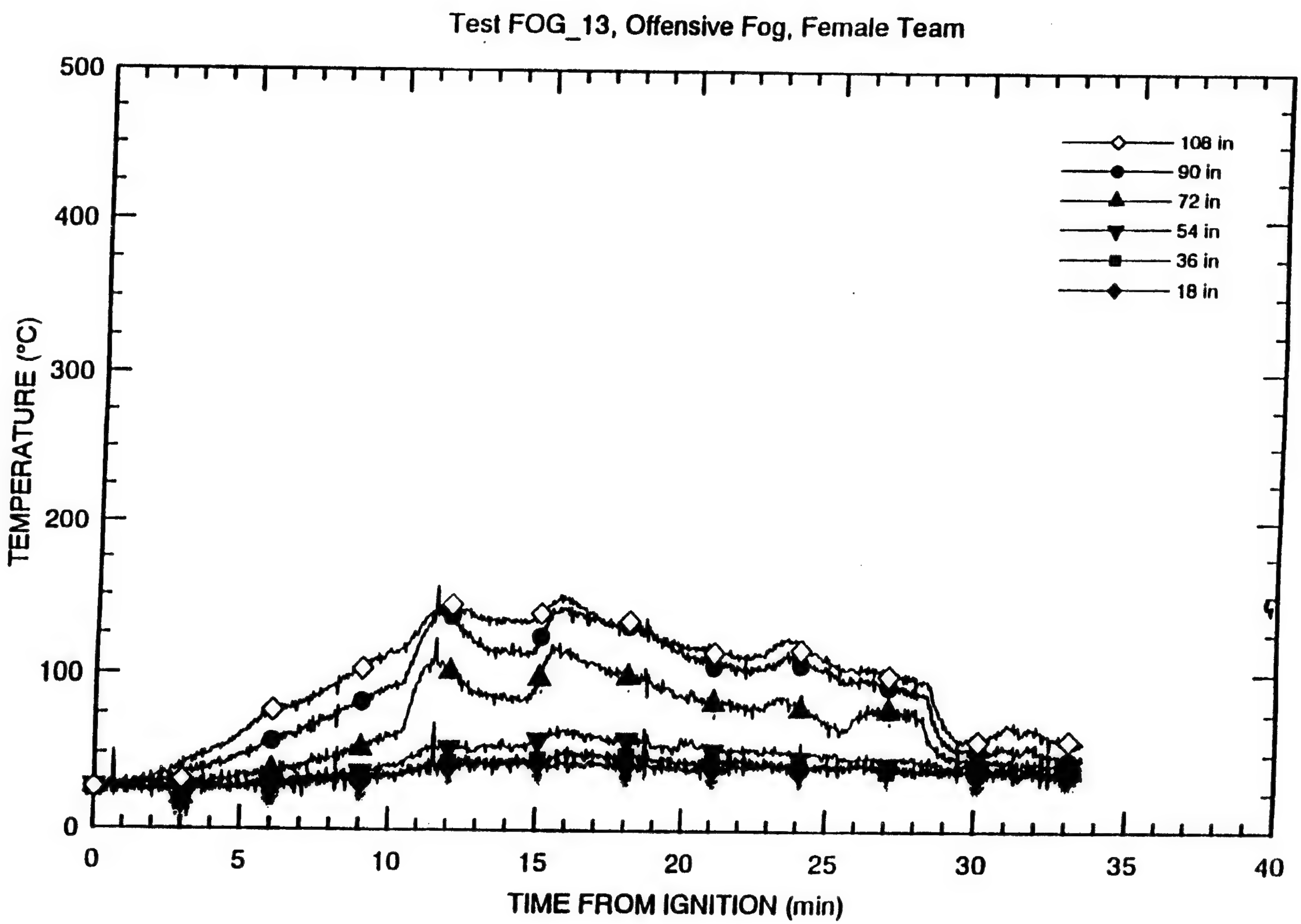


Fig. B39 - Starboard inner (2-21-1) thermocouple tree for FOG_13

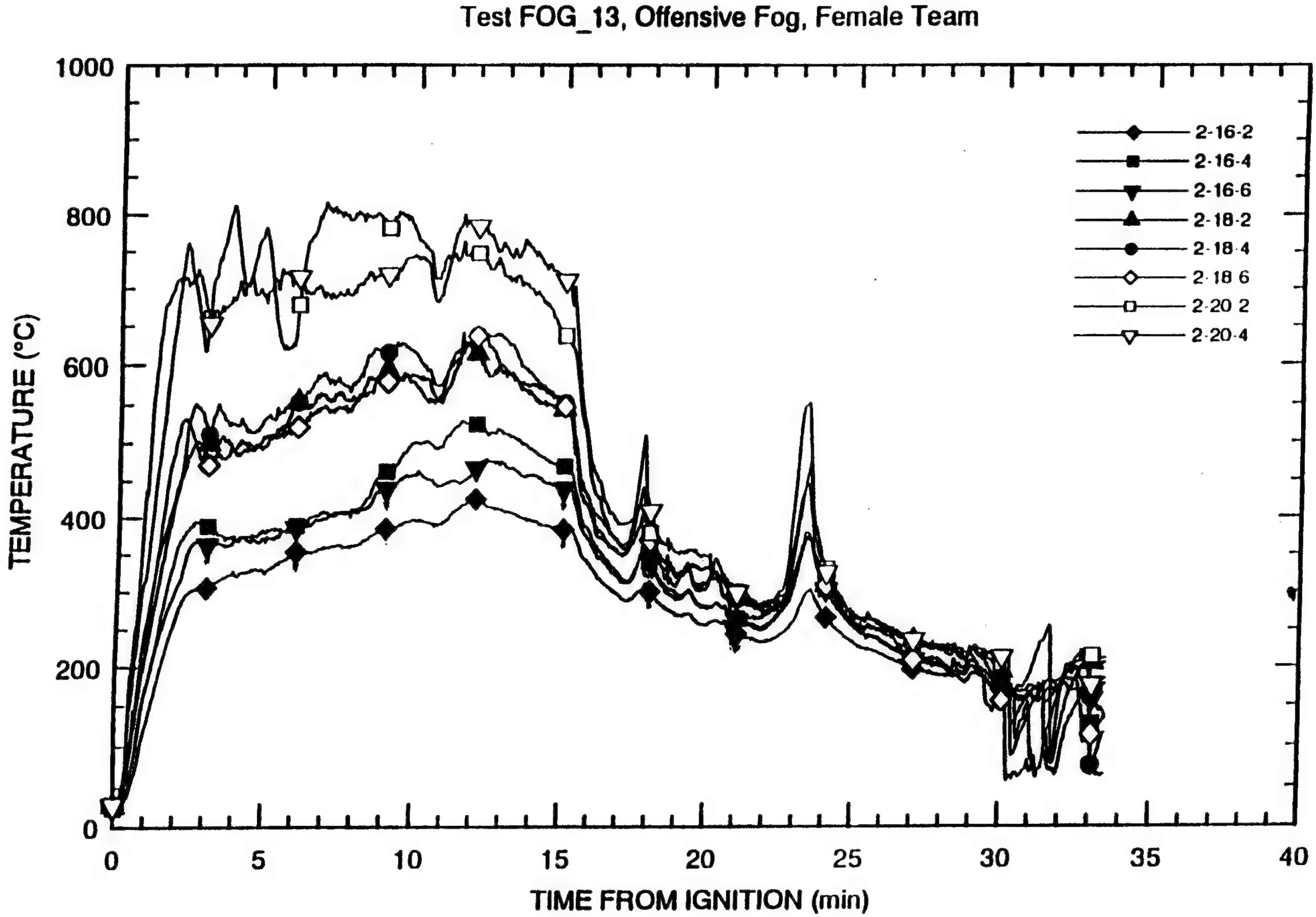


Fig. B40 - Burn room overhead temperatures for FOG_13

Test FOG_13, Offensive Fog, Female Team

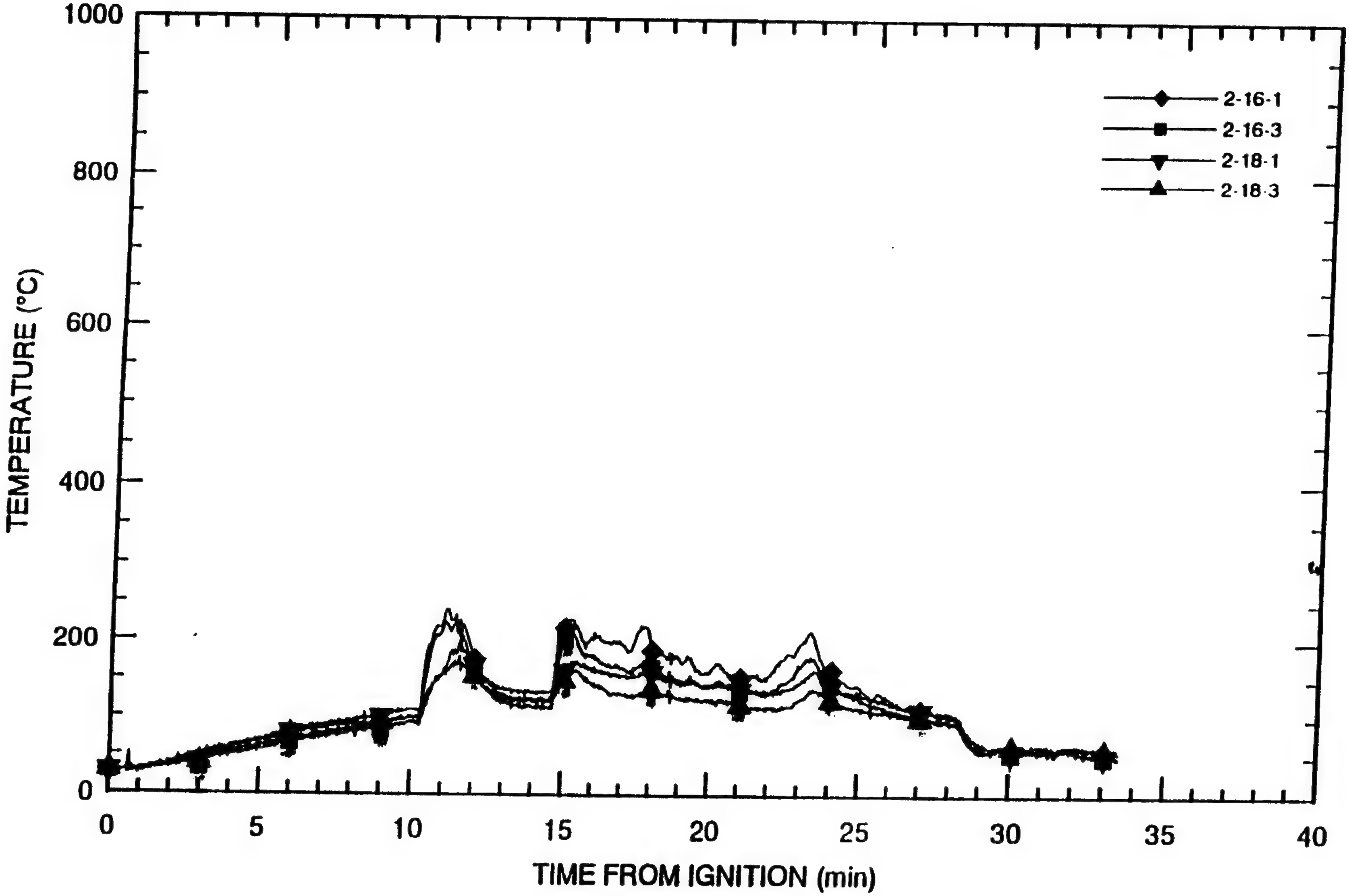


Fig. B41 - GSK overhead temperatures for FOG_13

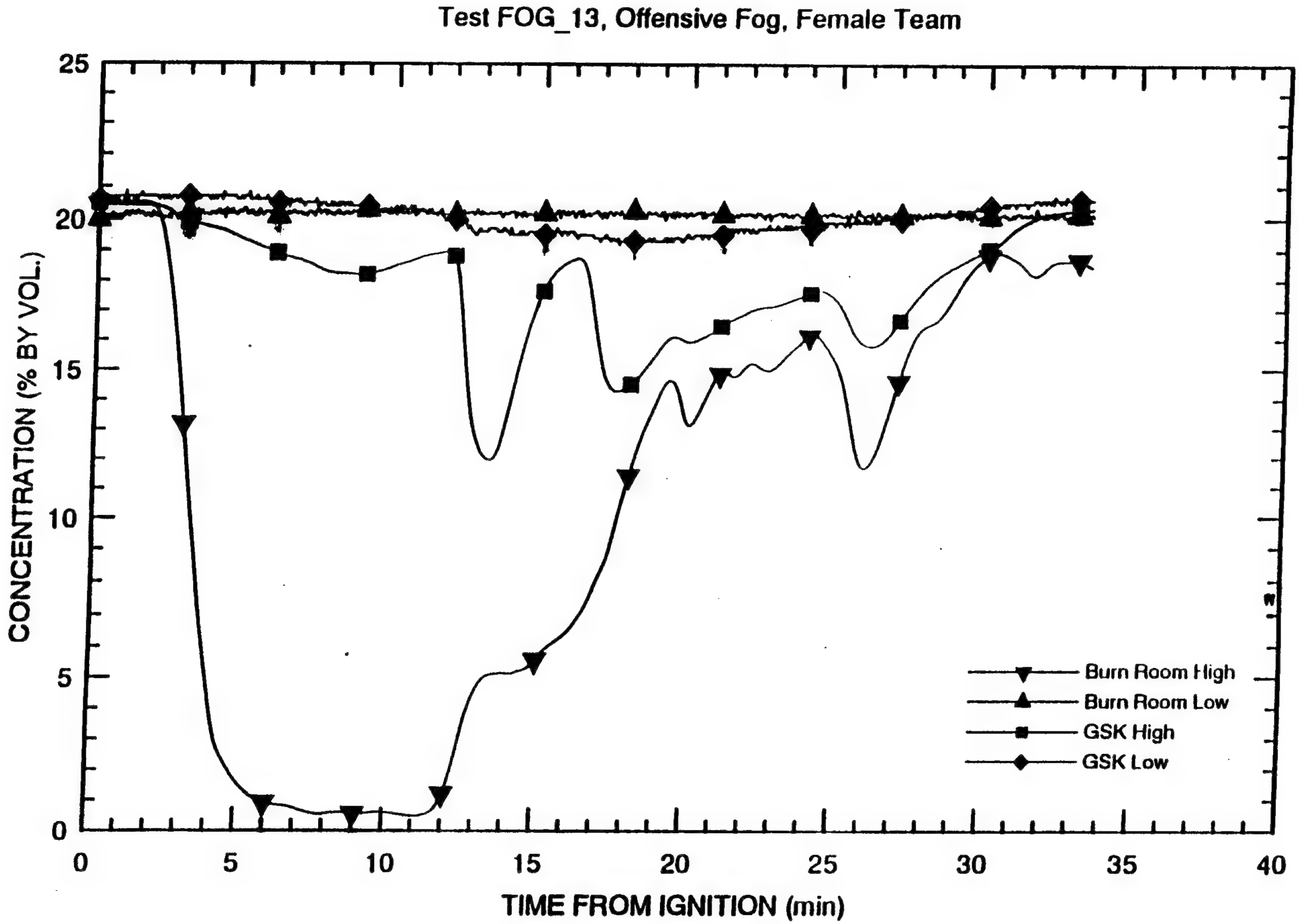


Fig. B42 - Oxygen (O_2) concentrations for FOG_13

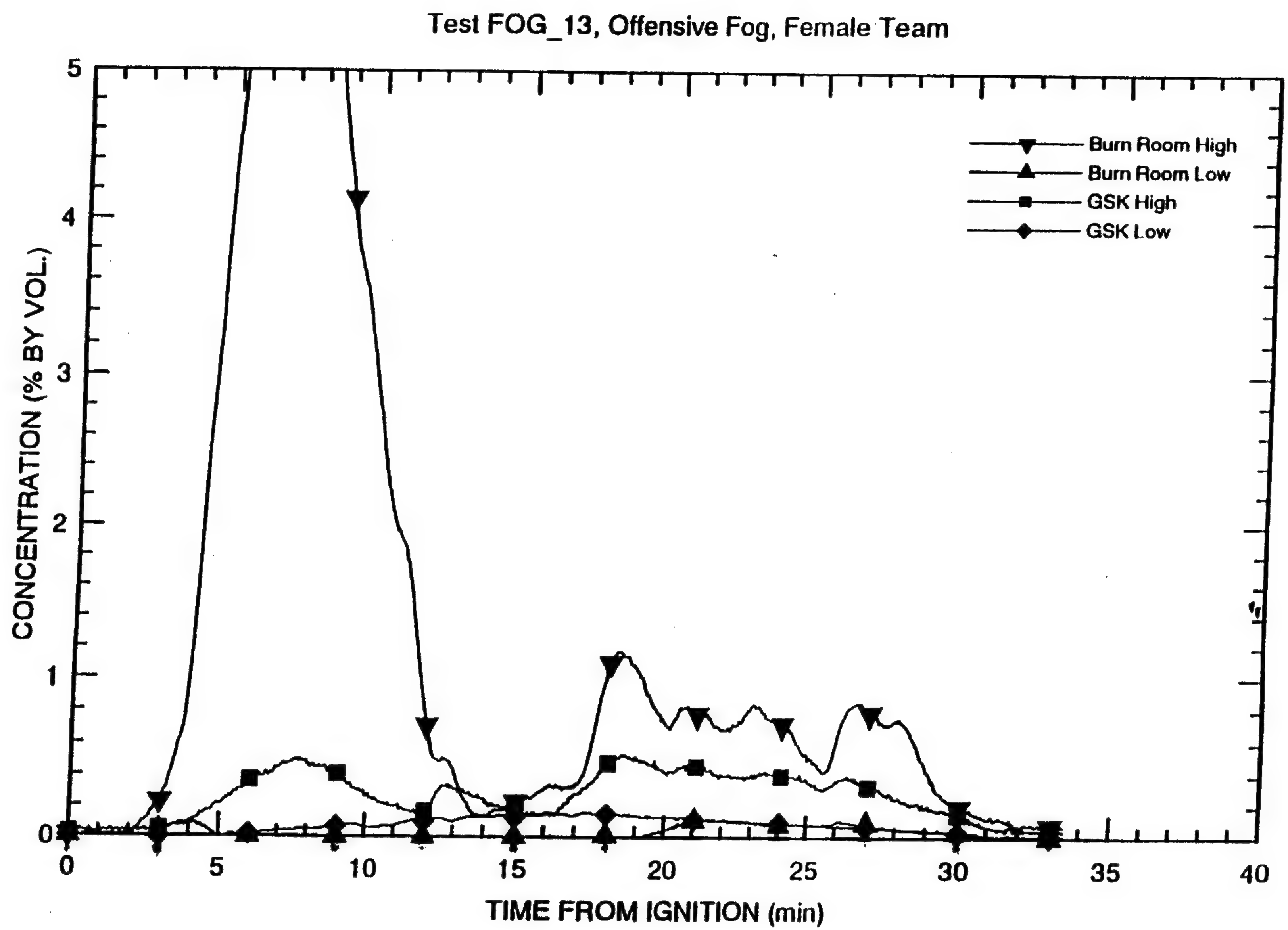


Fig. B43 - Carbon monoxide (CO) concentrations for FOG_13

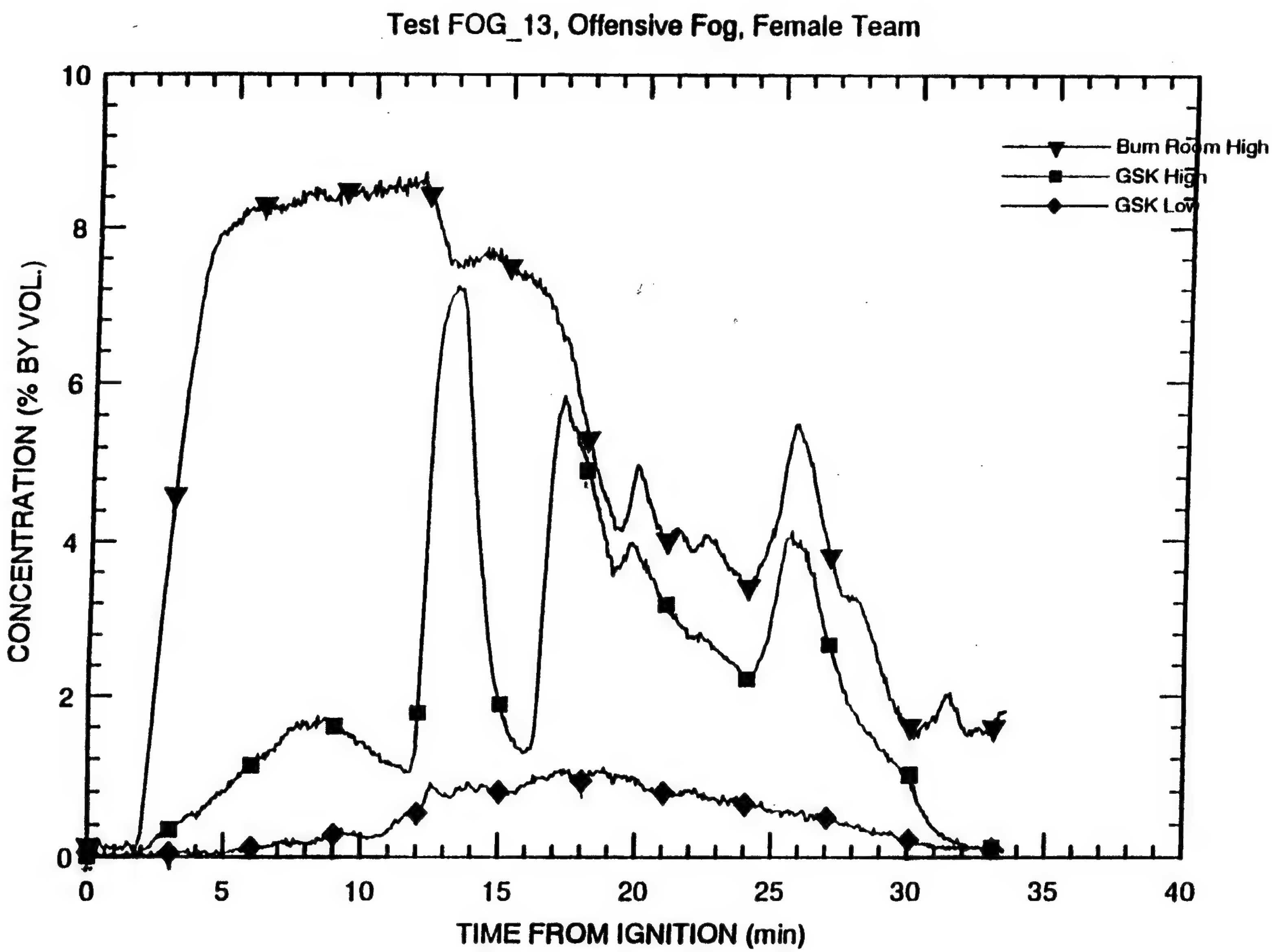


Fig. B44 - Carbon dioxide (CO_2) concentrations for FOG_13

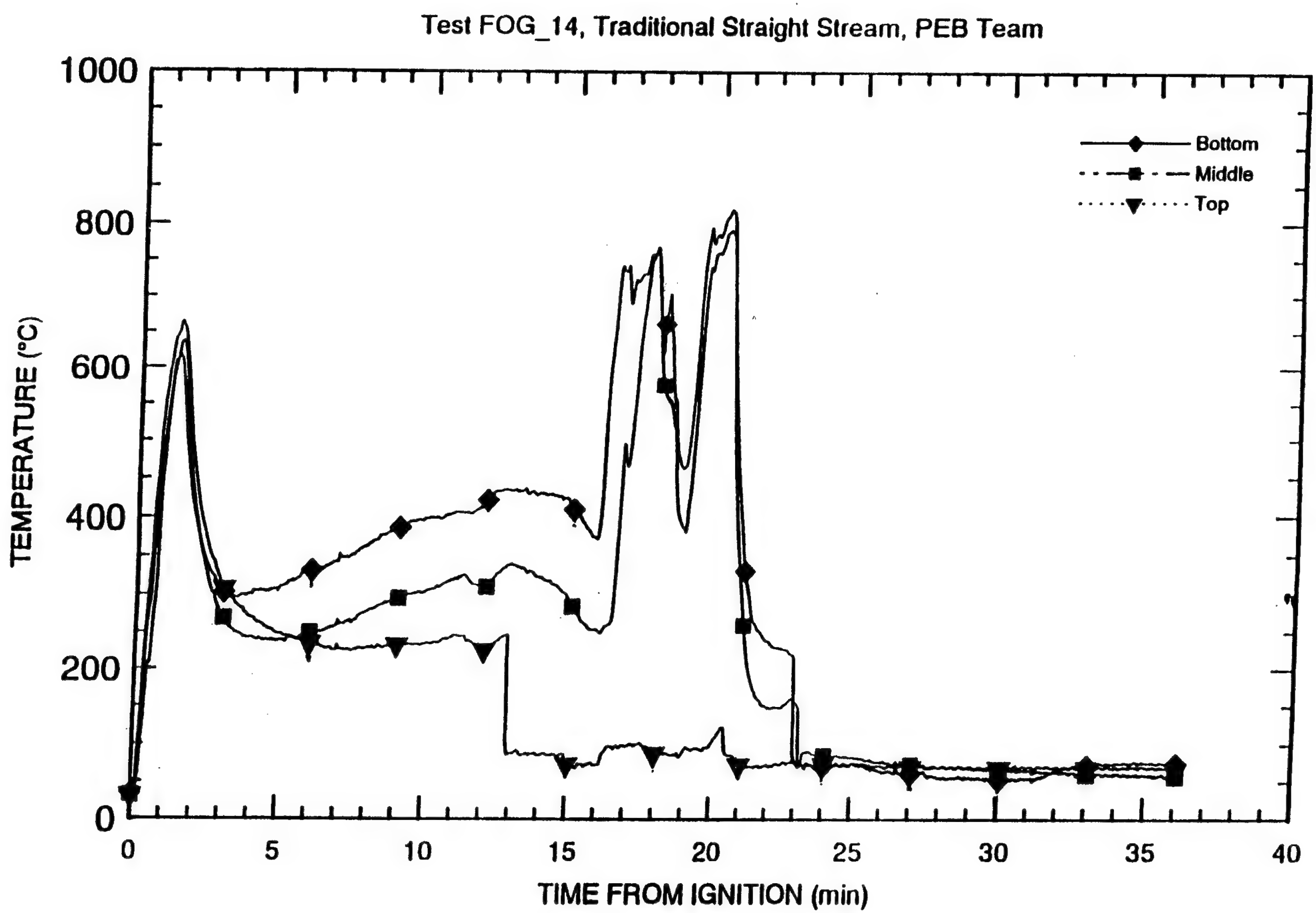


Fig. B45 - Wood crib #1 thermocouples for FOG_14

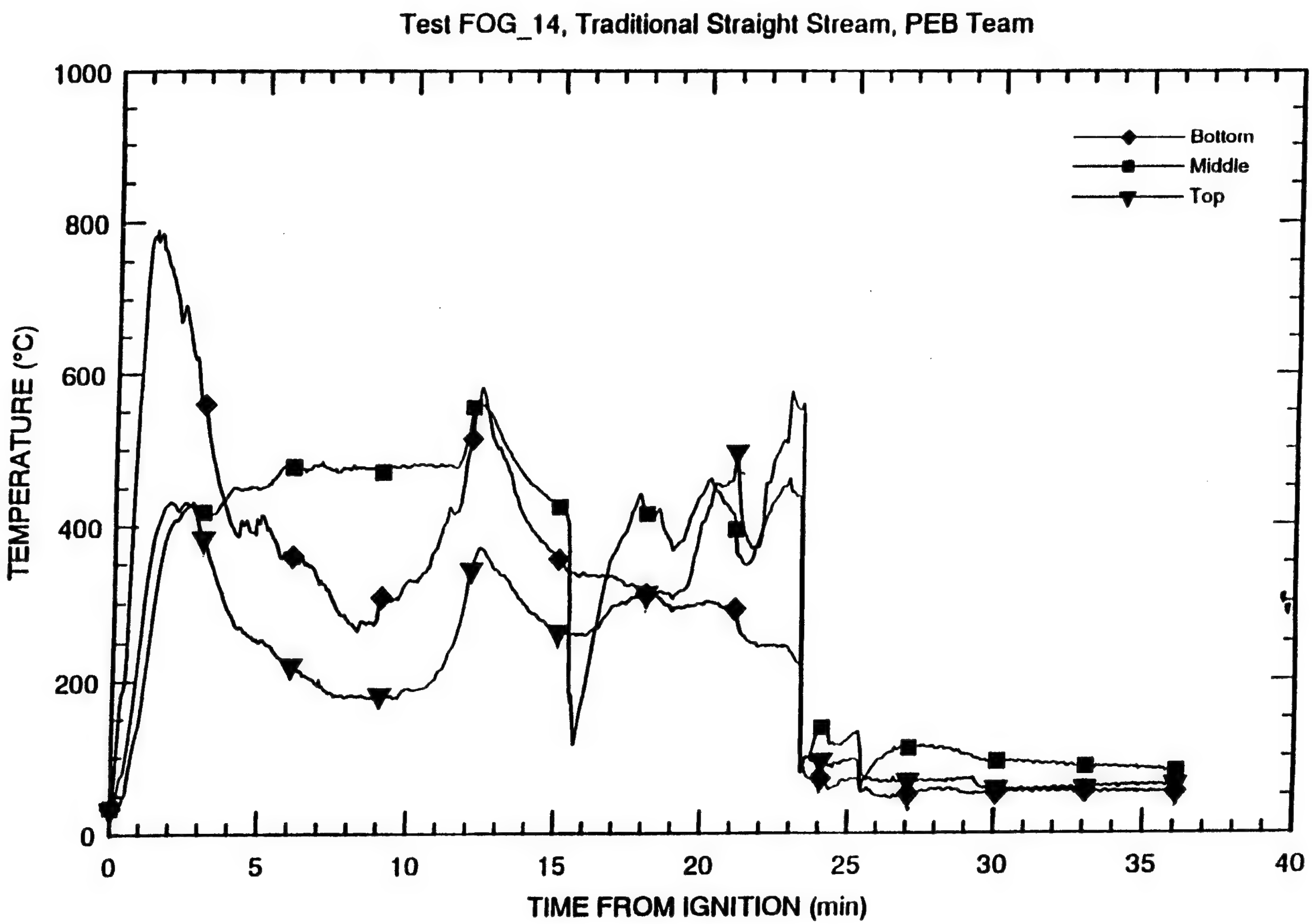


Fig. B46 - Wood crib #2 thermocouples for FOG_14

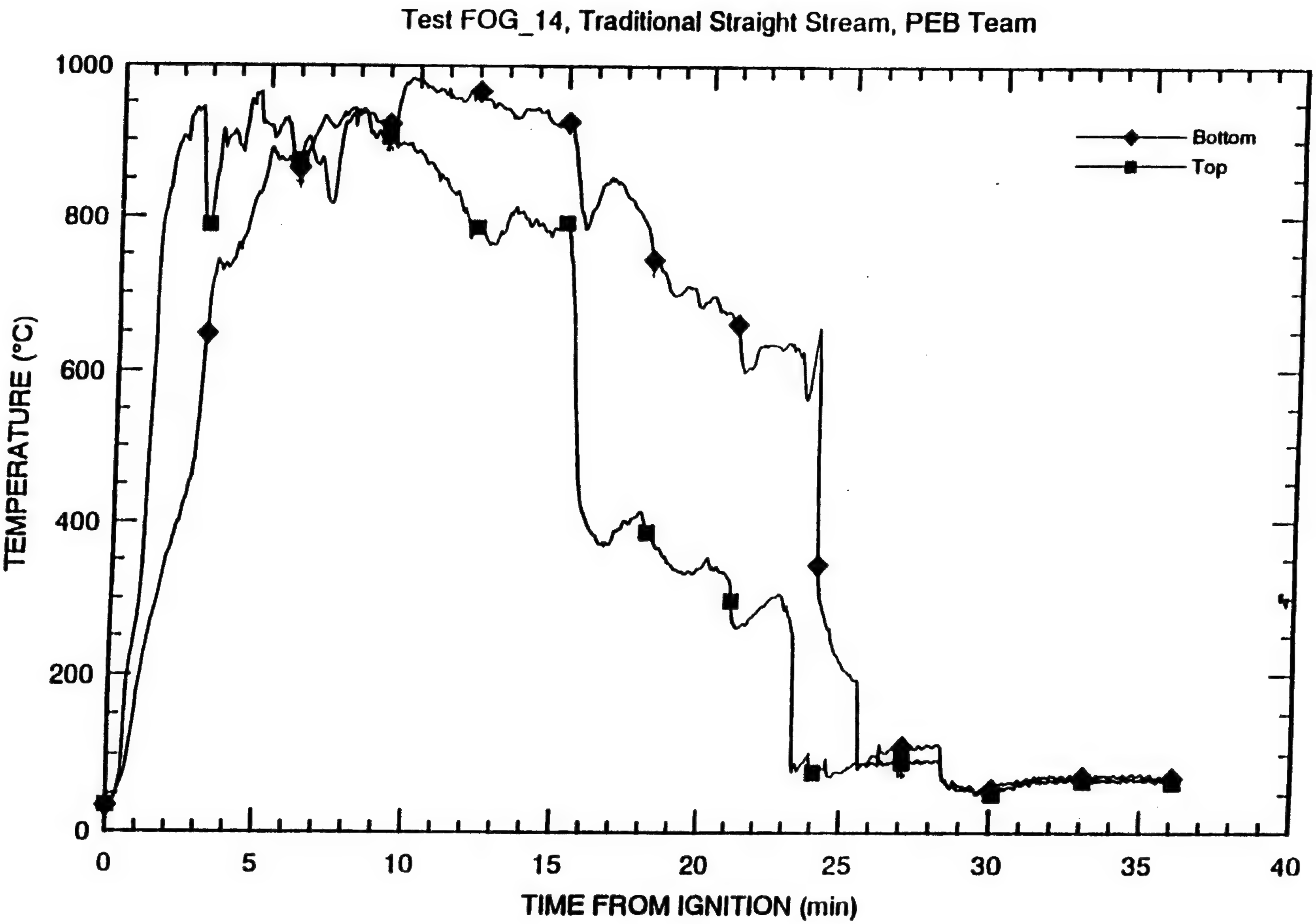


Fig. B47 - Wood crib #3 thermocouples for FOG_14

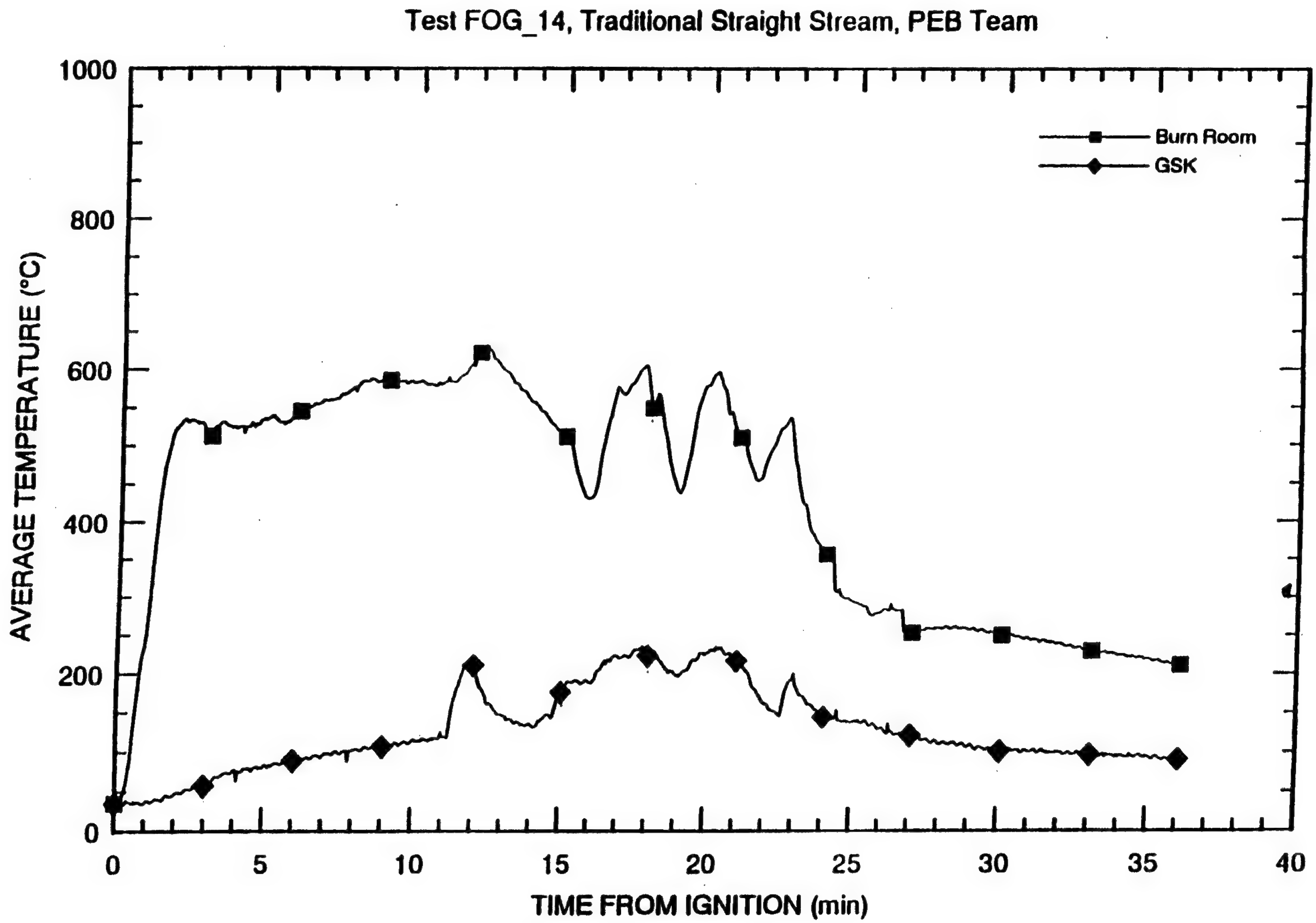


Fig. B48 - Average of overhead thermocouples for FOG_14

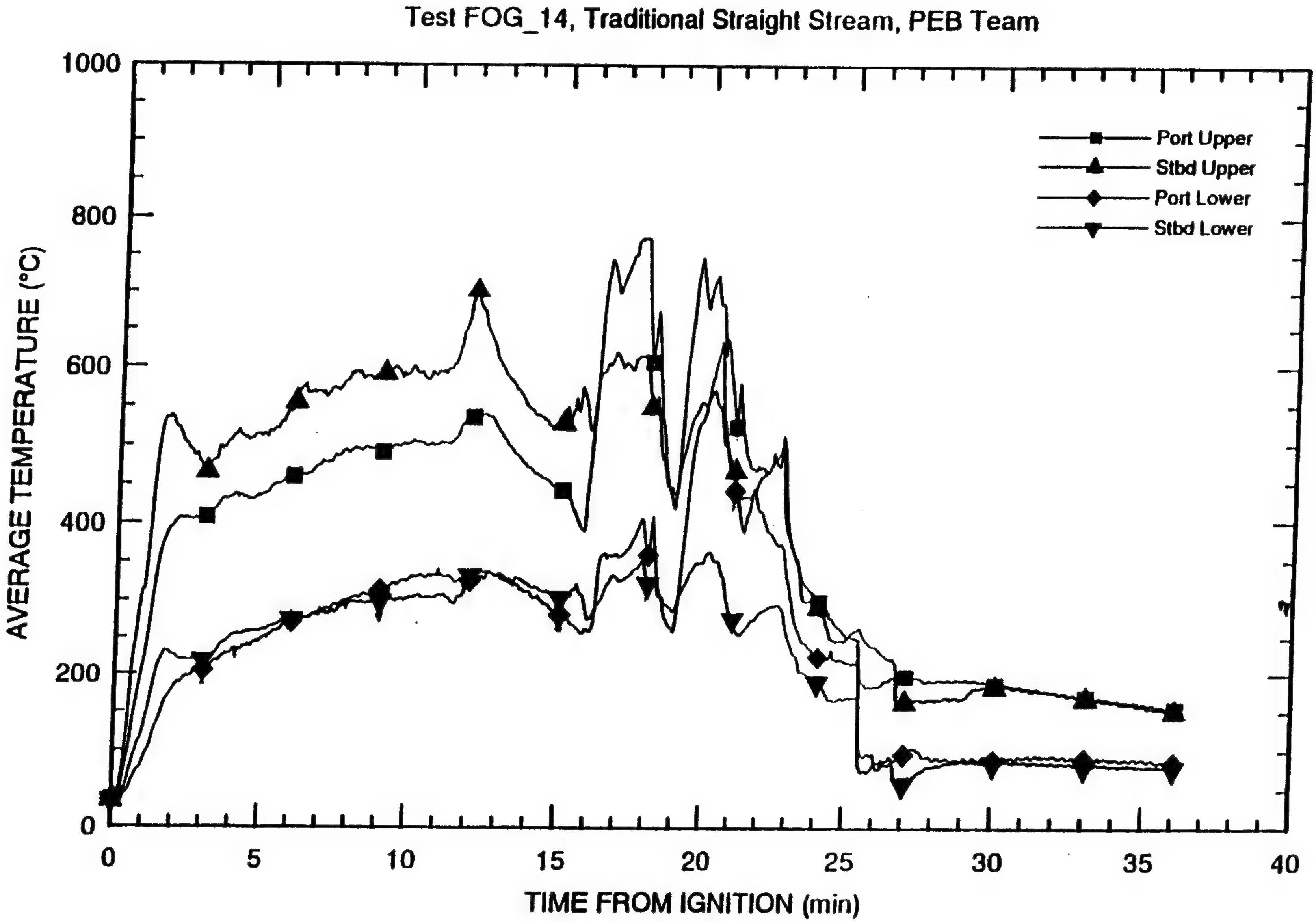


Fig. B49 - Burn room thermocouple string averages (upper vs. lower) for FOG_14

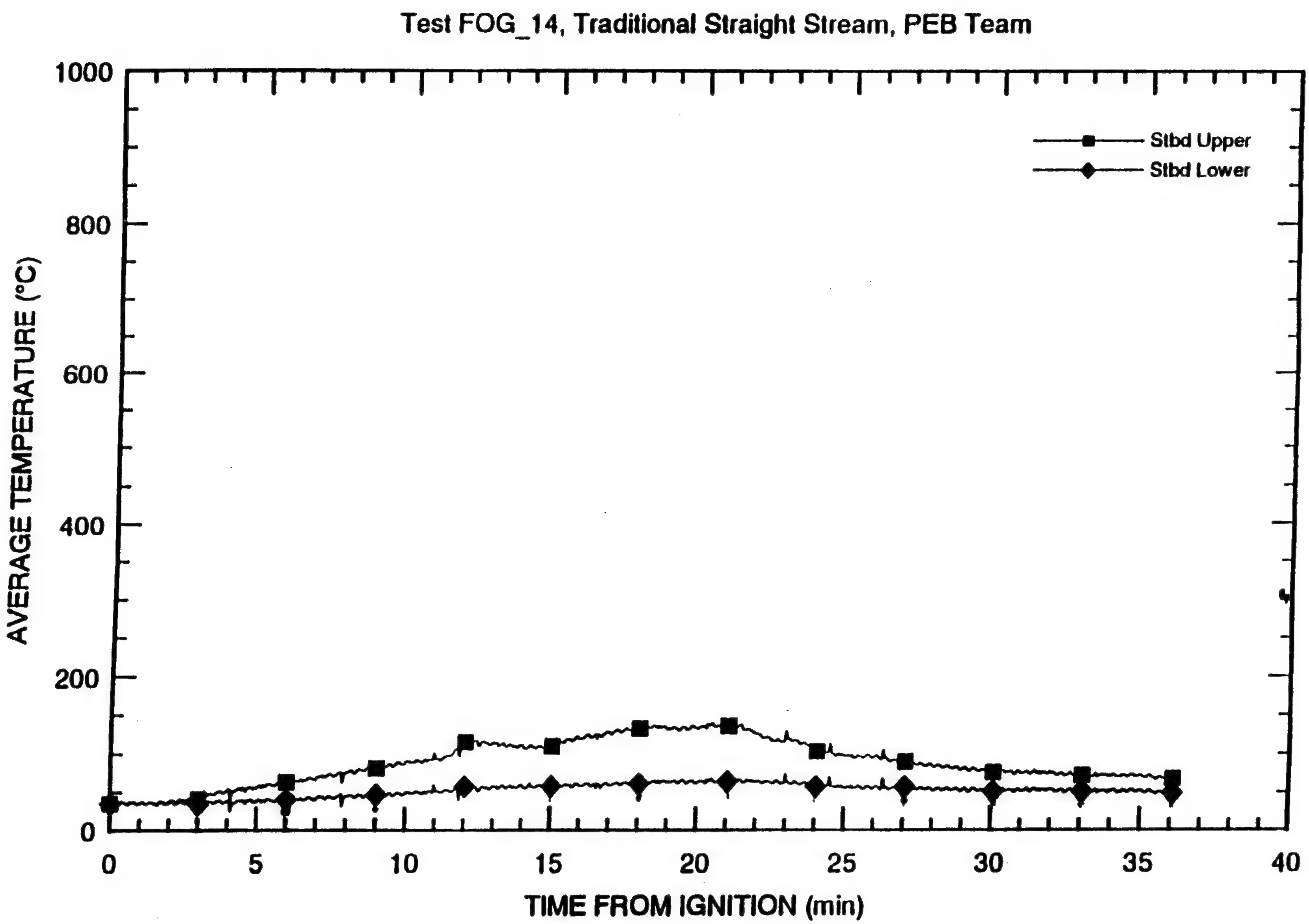


Fig. B50 - GSK thermocouple string averages (upper vs. lower) for FOG_14

Test FOG_14, Traditional Straight Stream, PEB Team

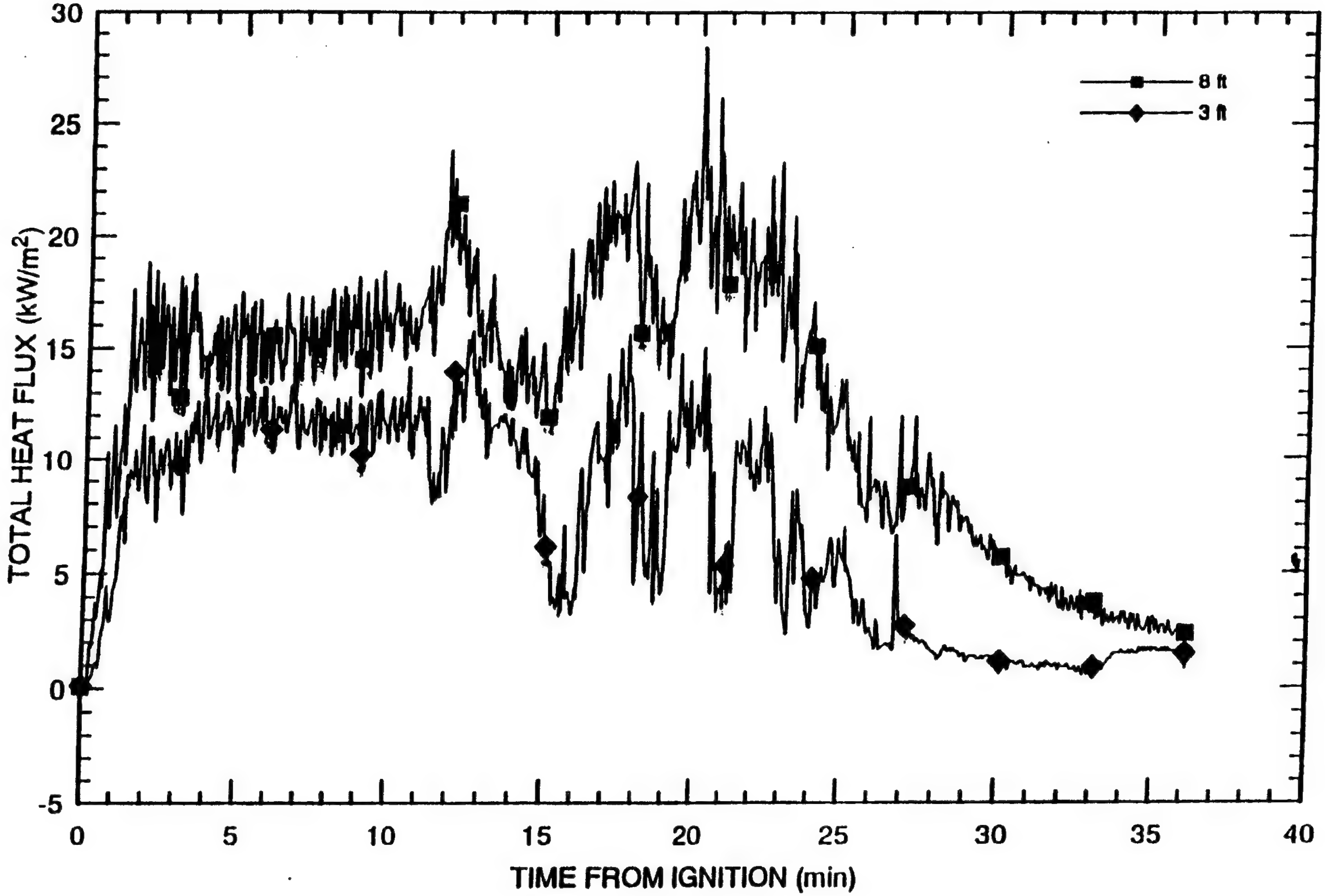


Fig. B51 - Burn room calorimeters for FOG_14

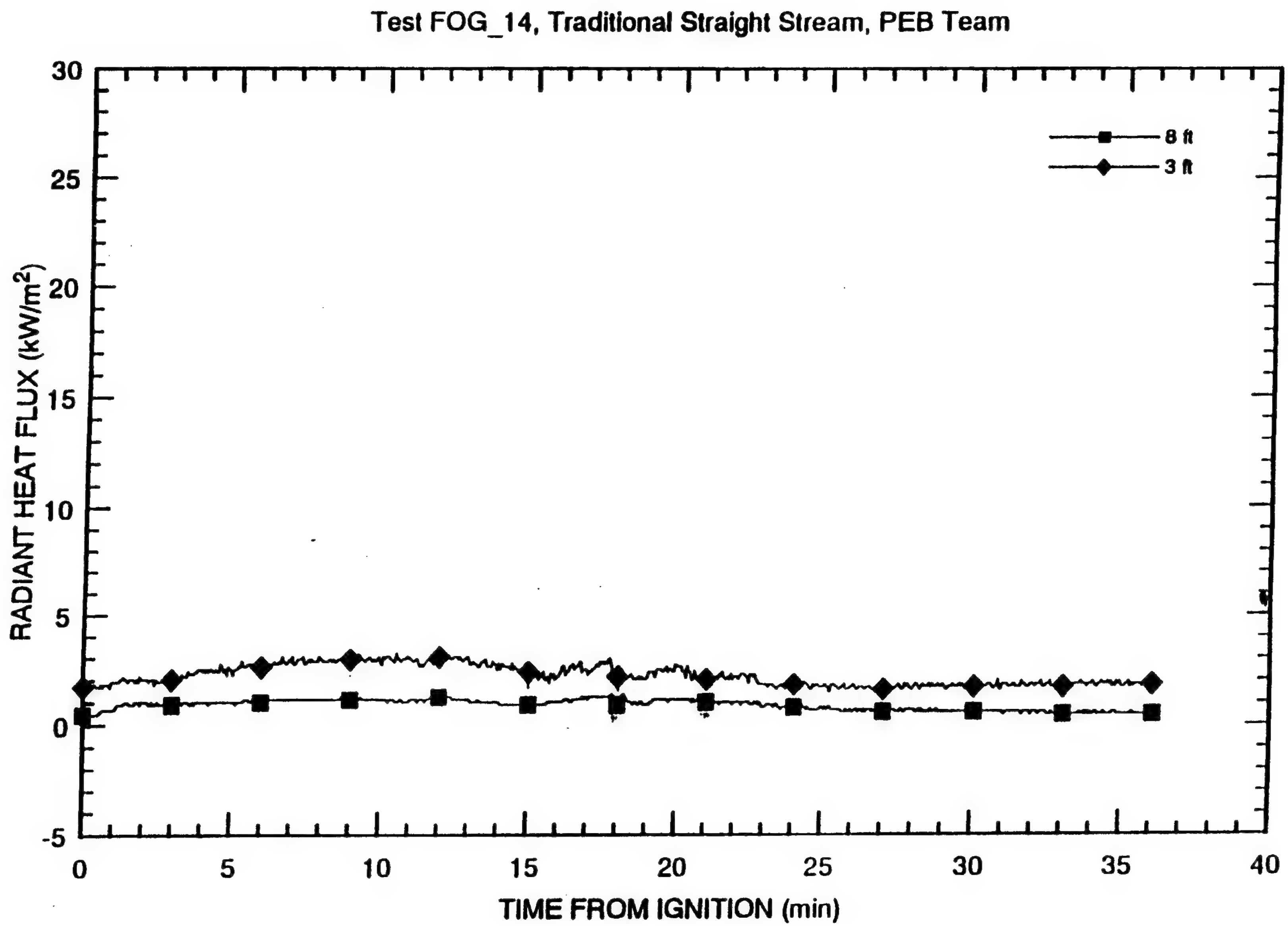


Fig. B52 - Burn room radiometers for FOG_14

Test FOG_14, Traditional Straight Stream, PEB Team

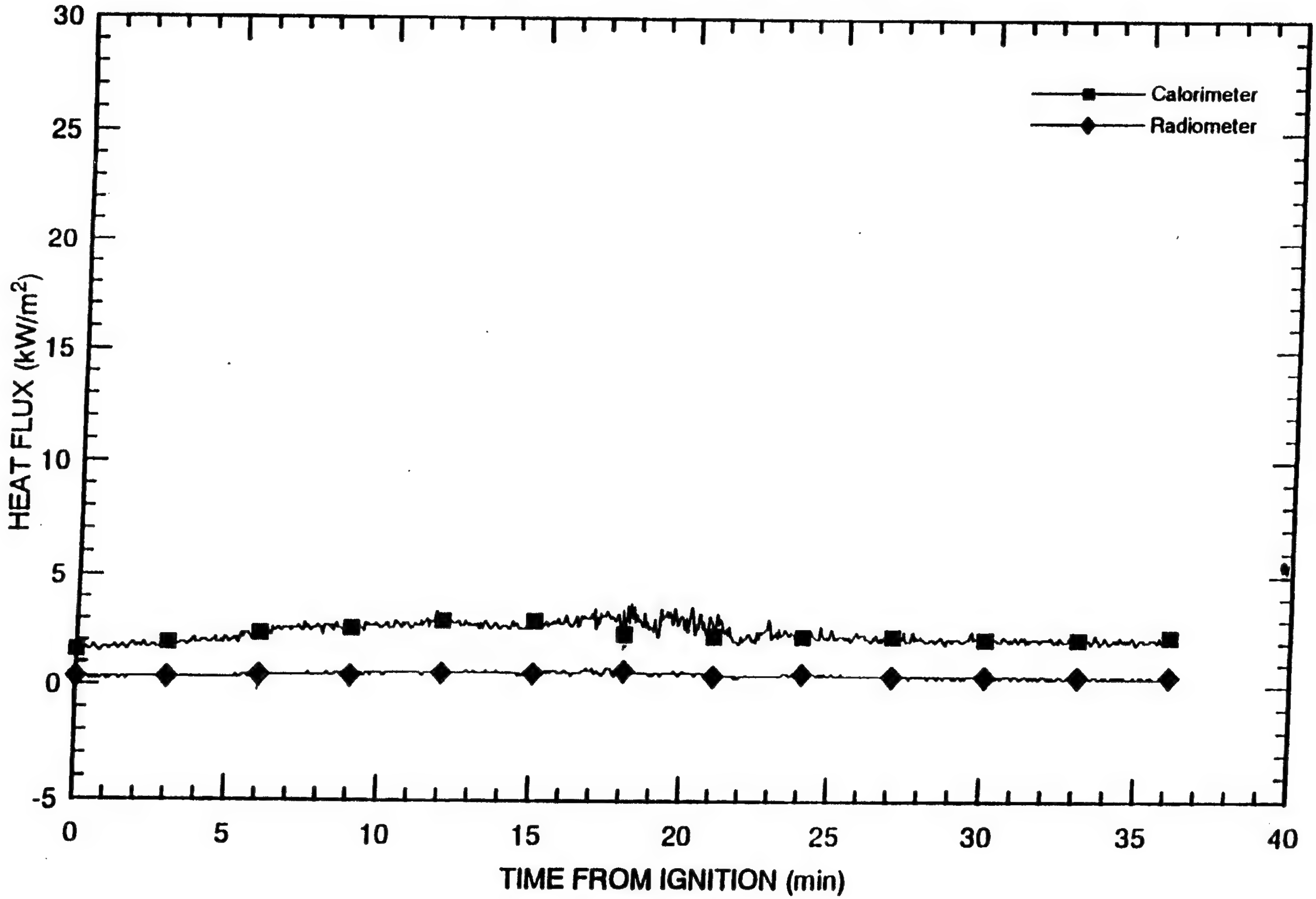


Fig. B53 - GSK radiometer and calorimeter for FOG_14

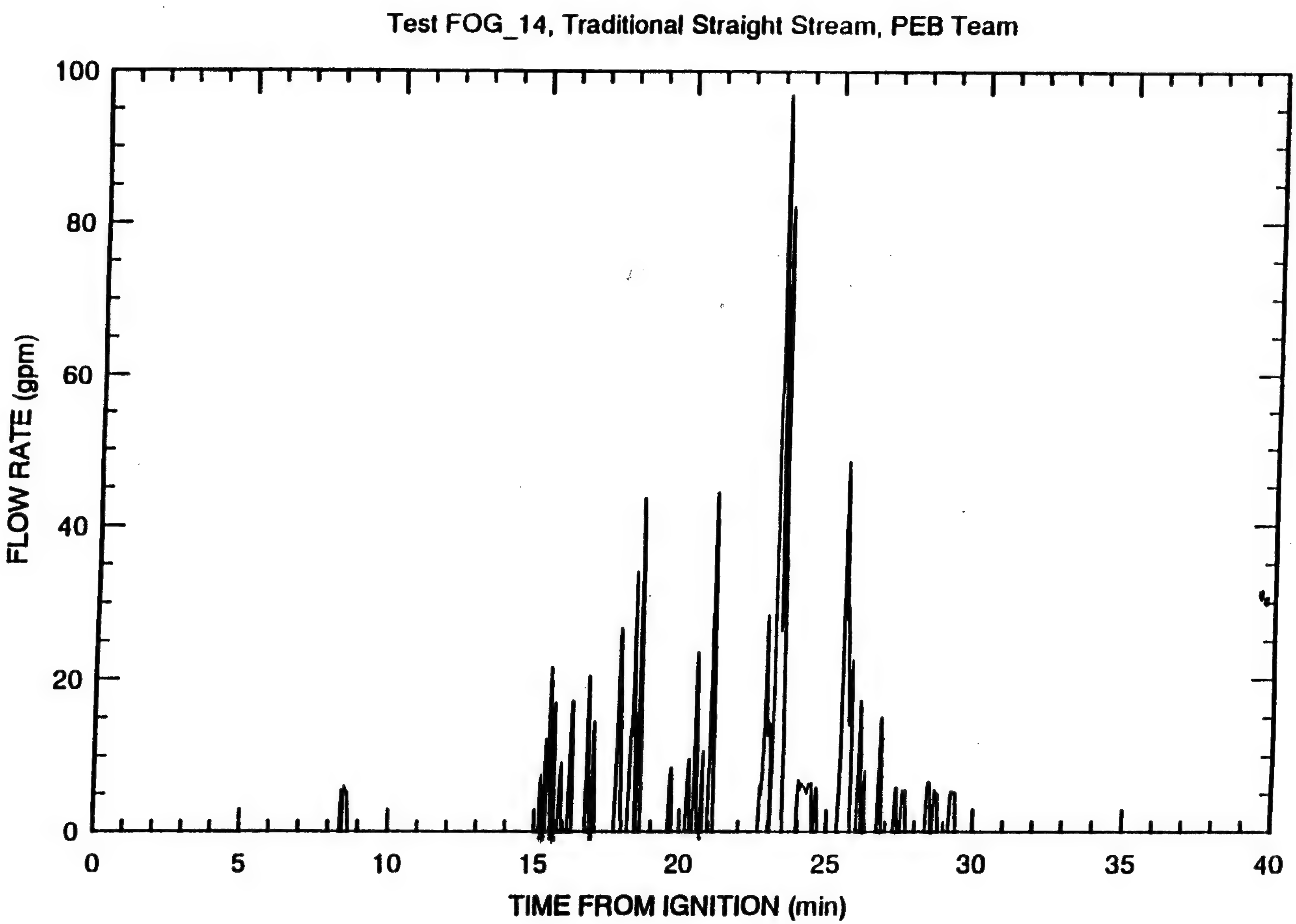


Fig. B54 - Water flow rate for FOG_14

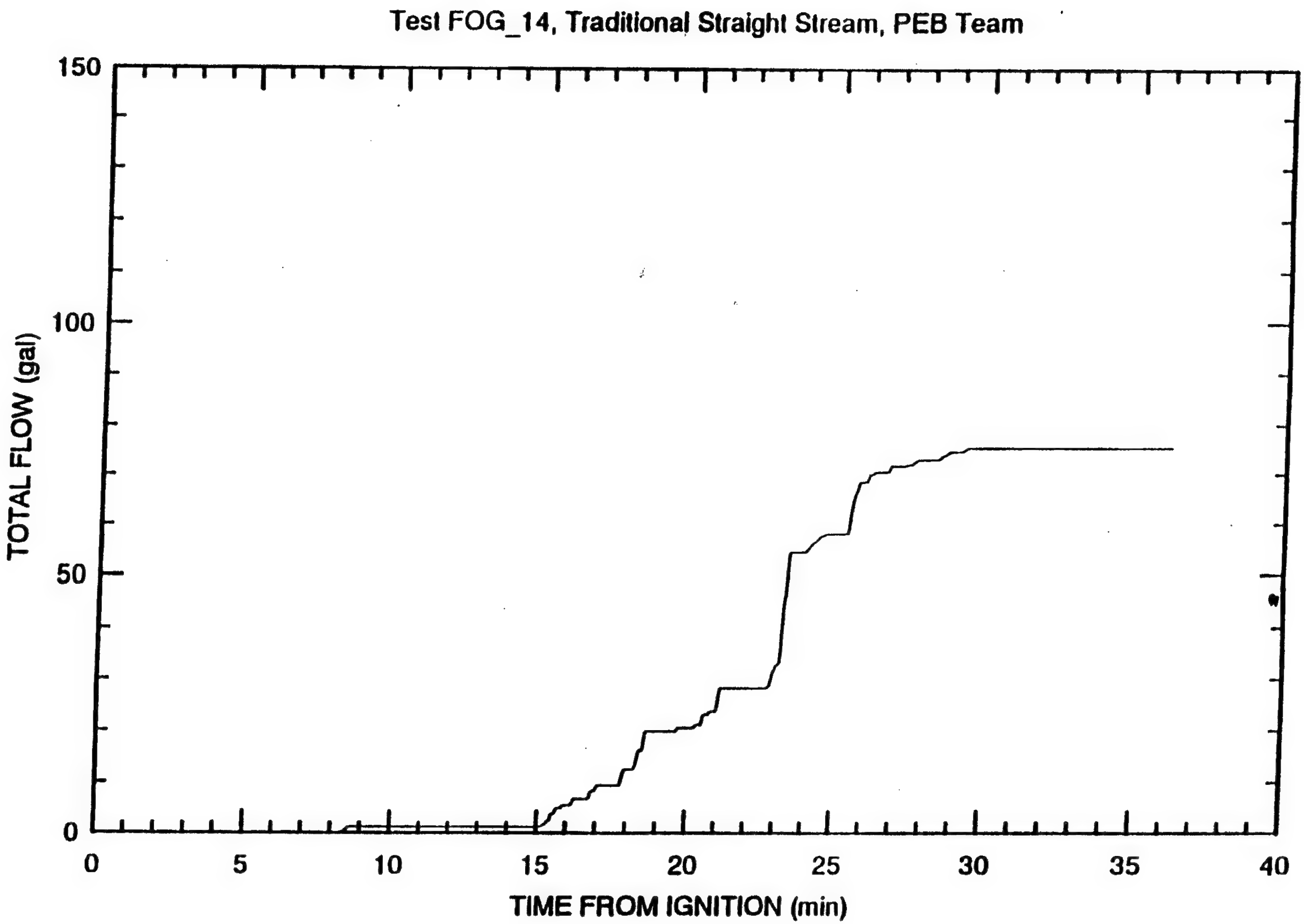


Fig. B55 - Cumulative water flow for FOG_14

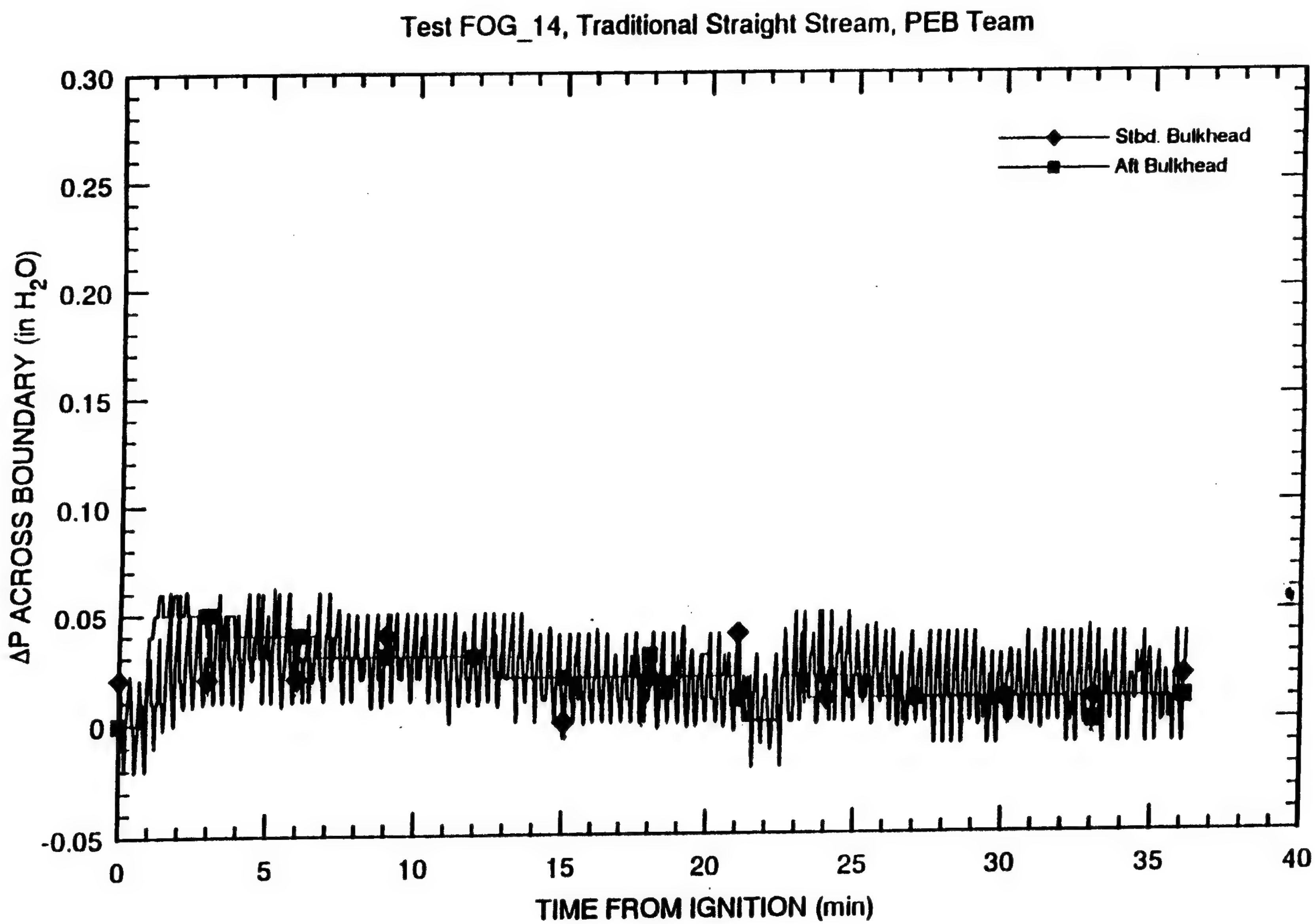


Fig. B56 - Pressure differential across burn room boundaries for FOG_14

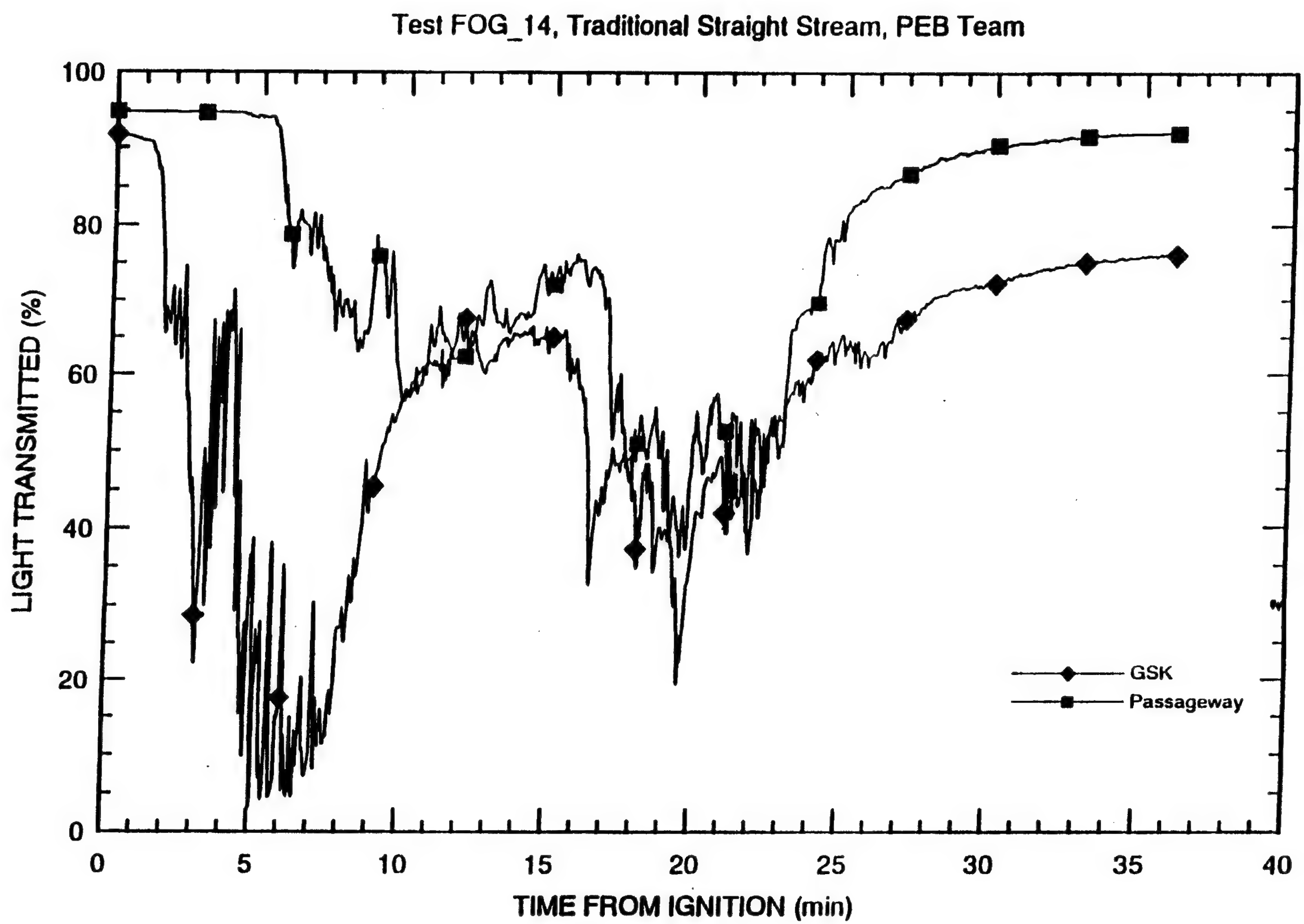


Fig. B57 - Smoke Obscuration for FOG_14

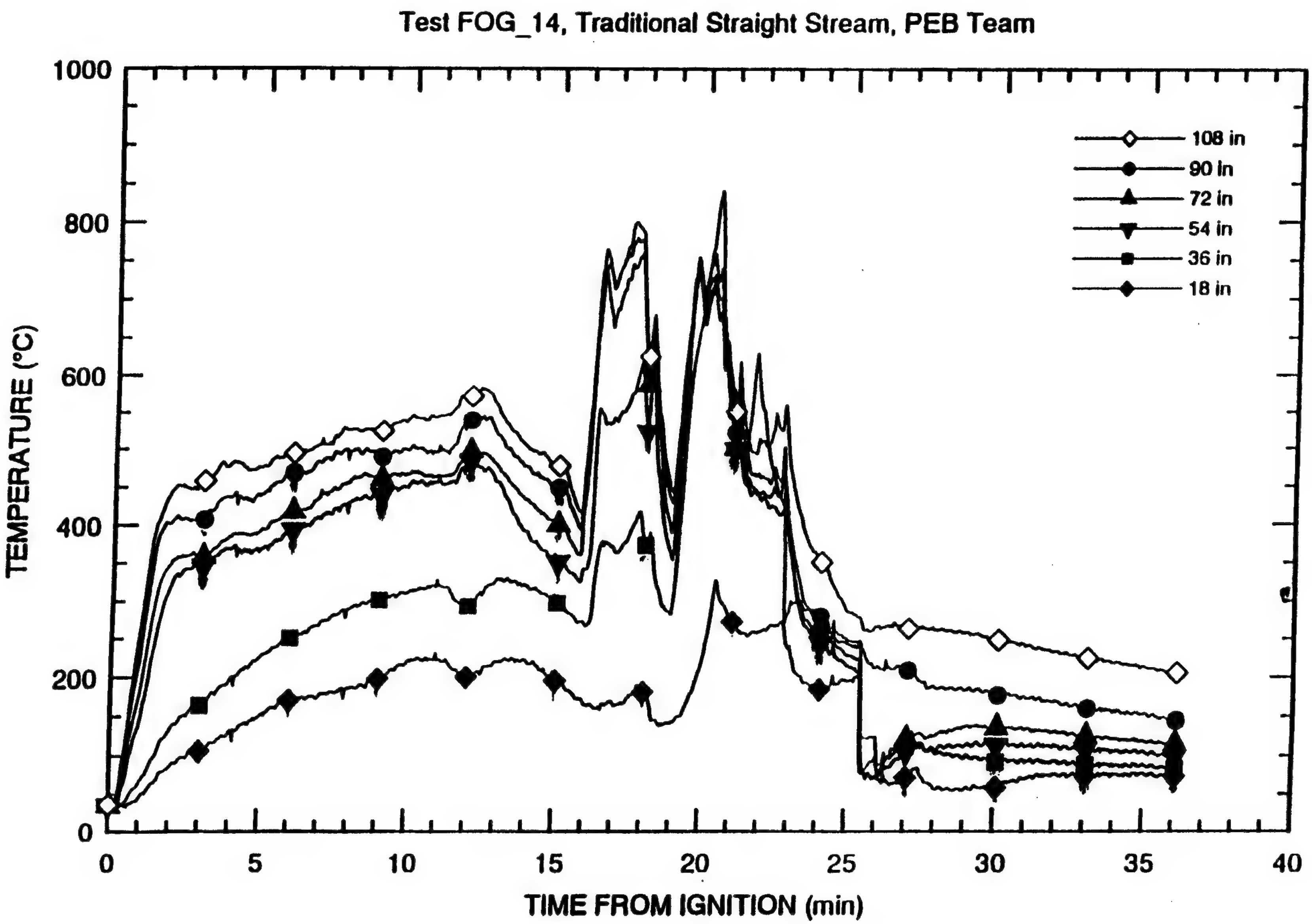


Fig. B58 - Port outer (2-18-2) thermocouple tree for FOG_14

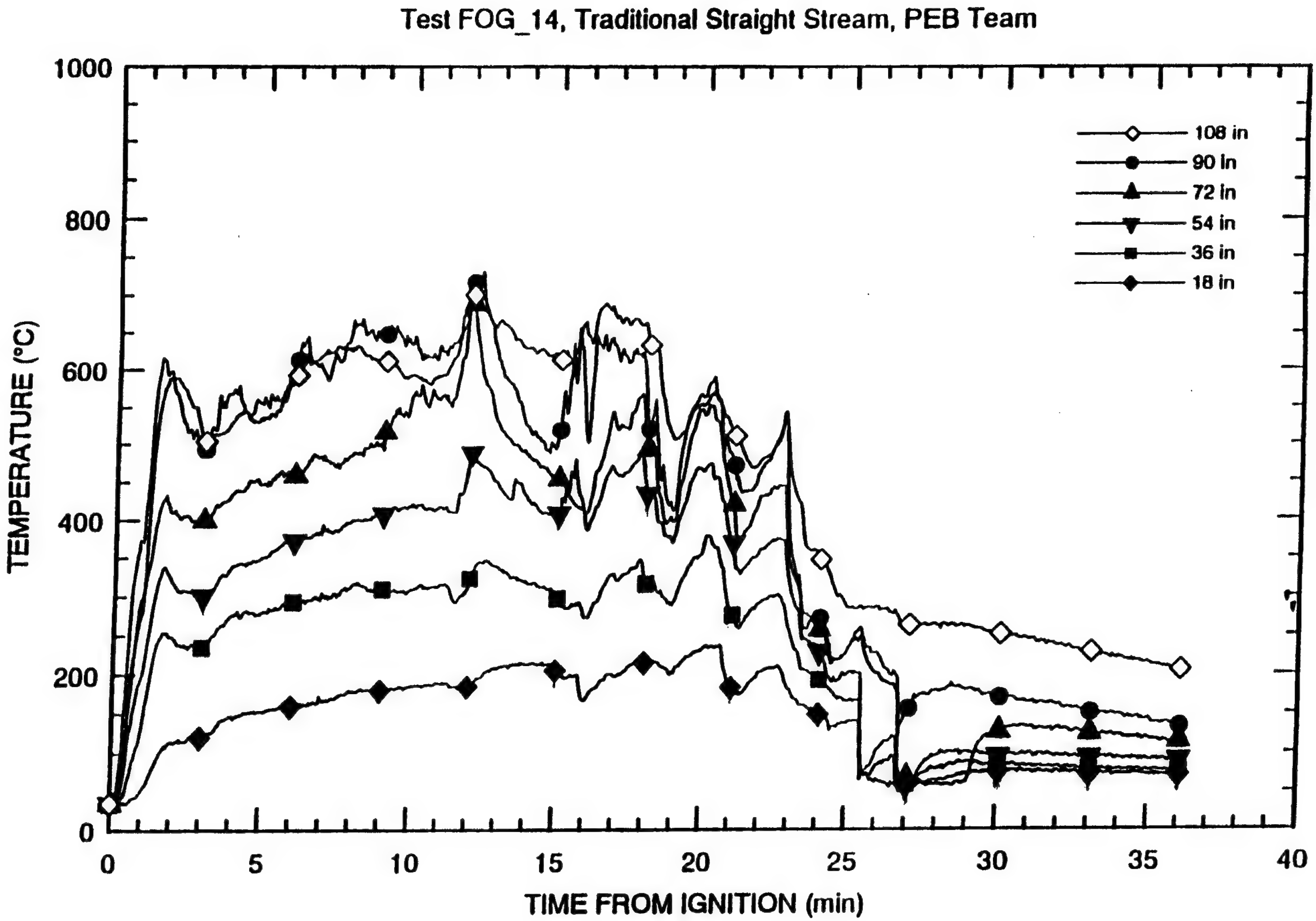


Fig. B59 - Port inner (2-19-0) thermocouple tree for FOG_14

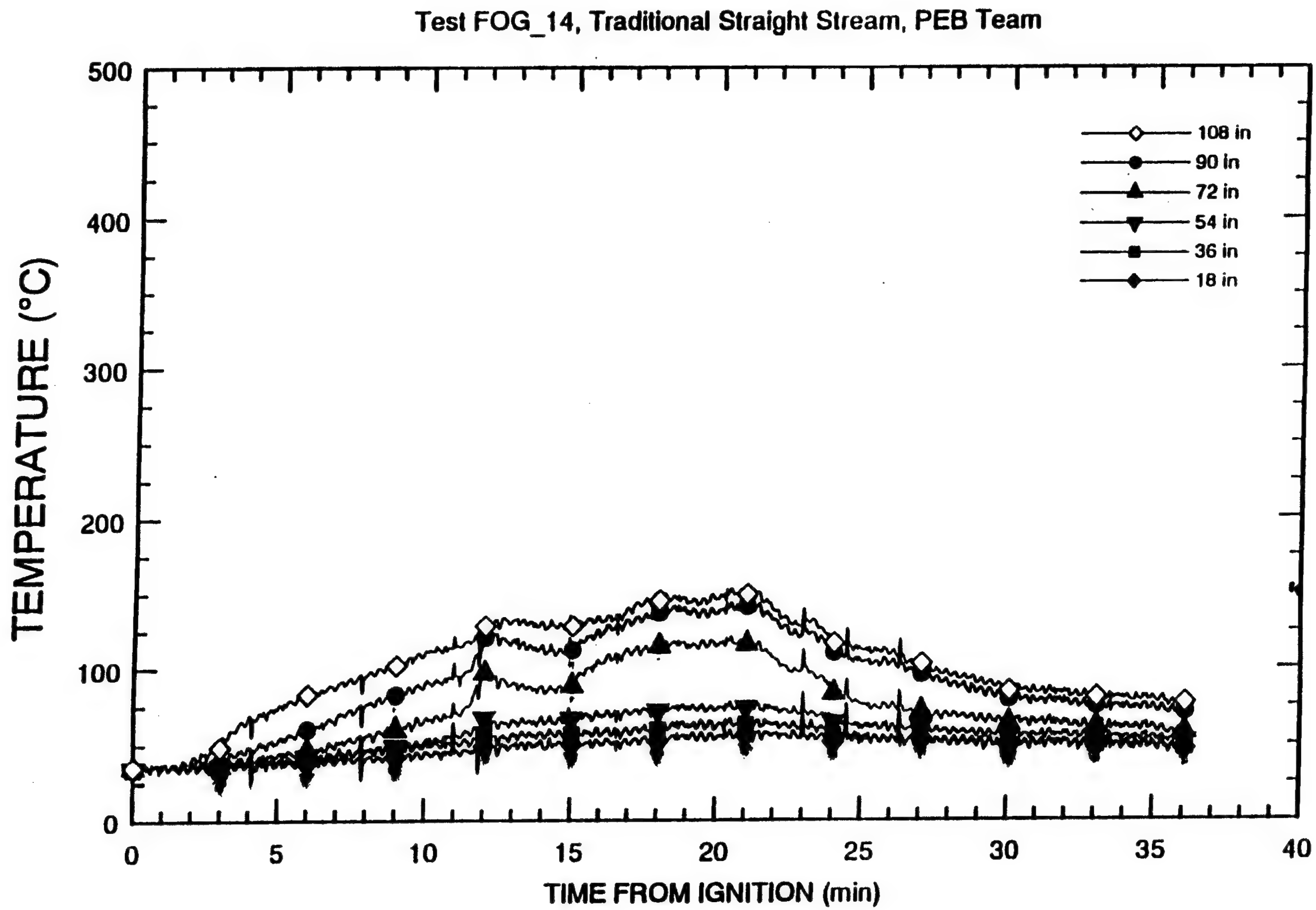


Fig. B60 - Starboard outer (2-21-3) thermocouple tree for FOG_14

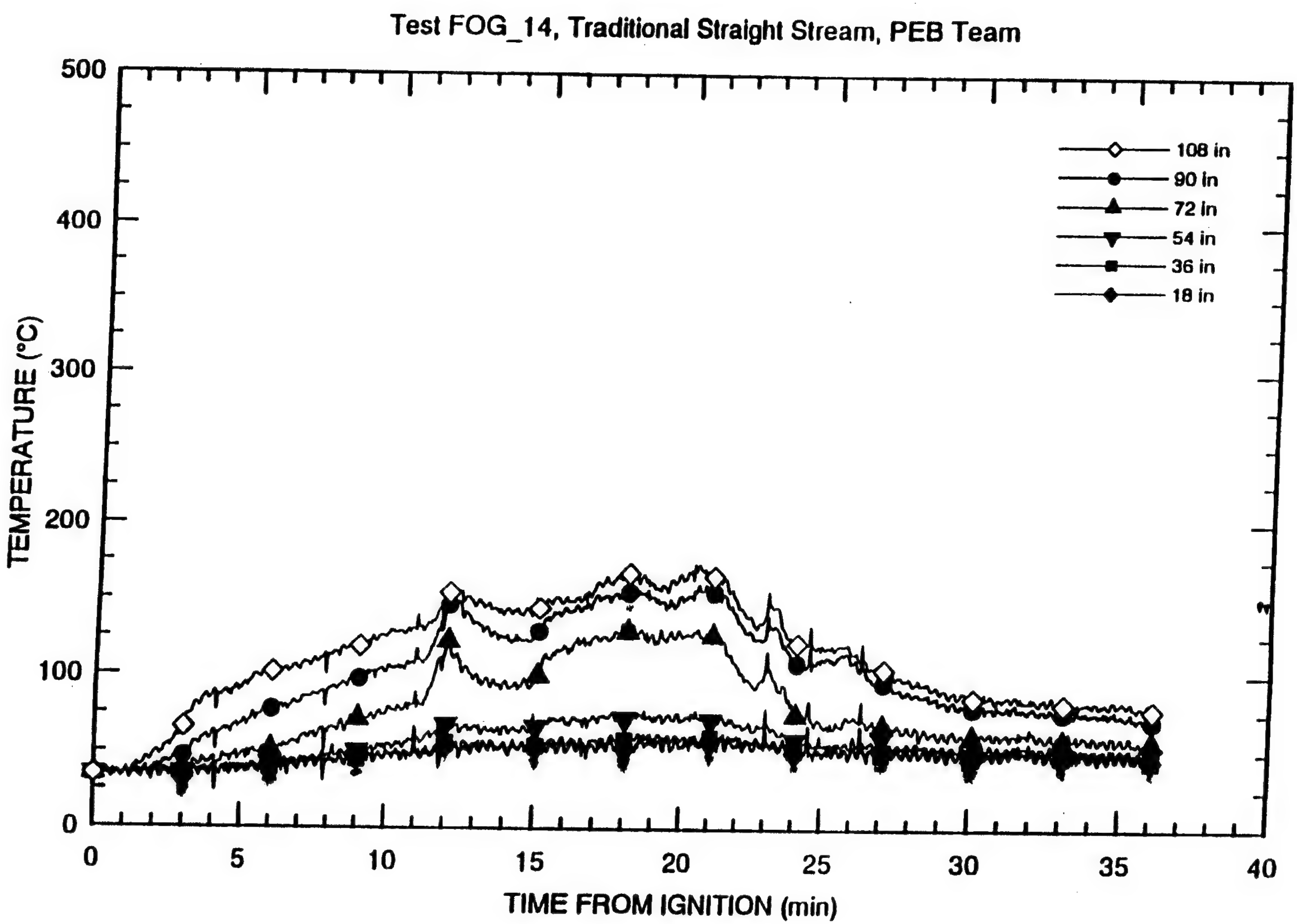


Fig. B61 - Starboard inner (2-21-1) thermocouple tree for FOG_14

Test FOG_14, Traditional Straight Stream, PEB Team

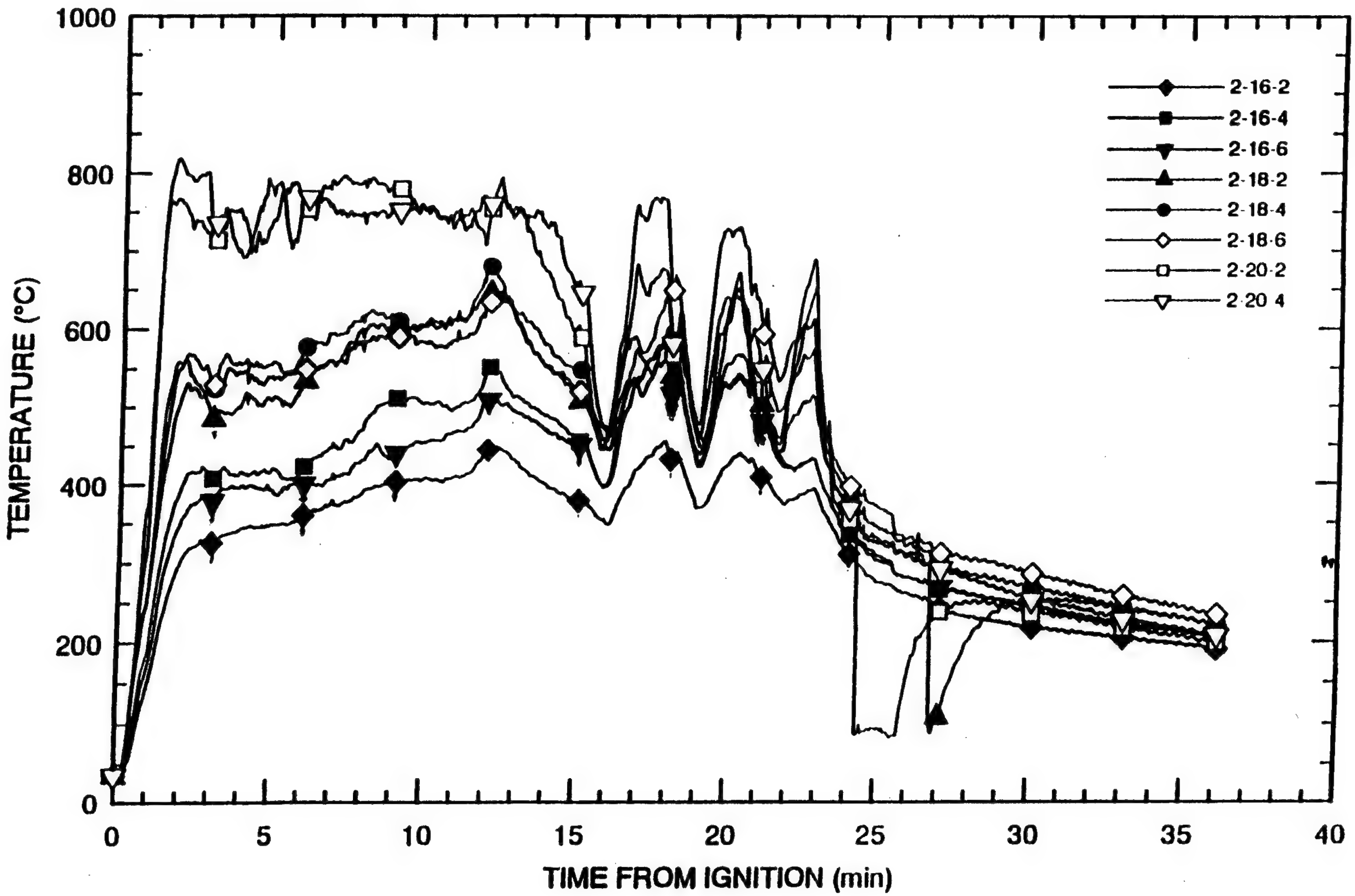


Fig. B62 - Burn room overhead temperatures for FOG_14

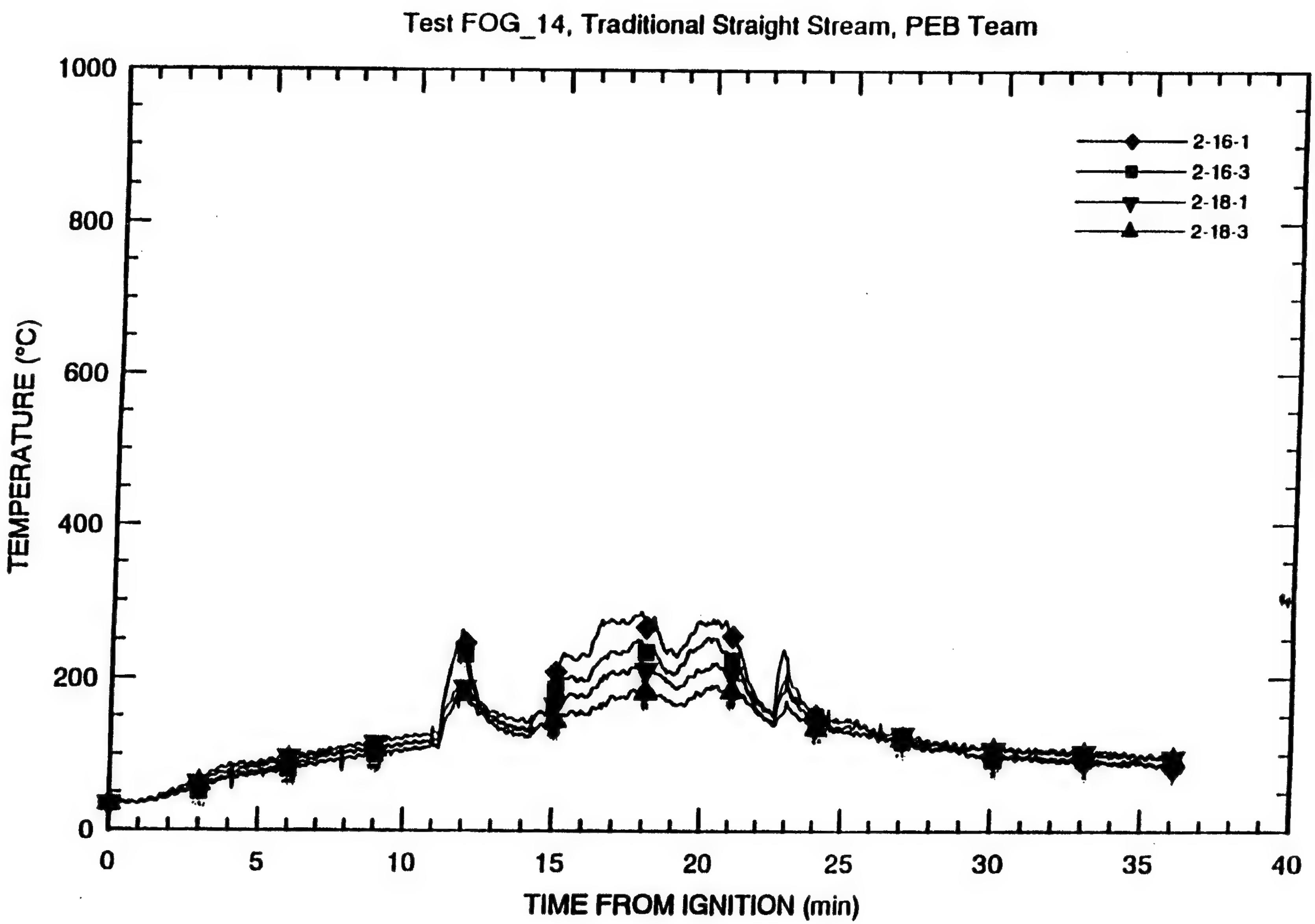


Fig. B63 - GSK overhead temperatures for FOG_14

Test FOG_14, Traditional Straight Stream, PEB Team

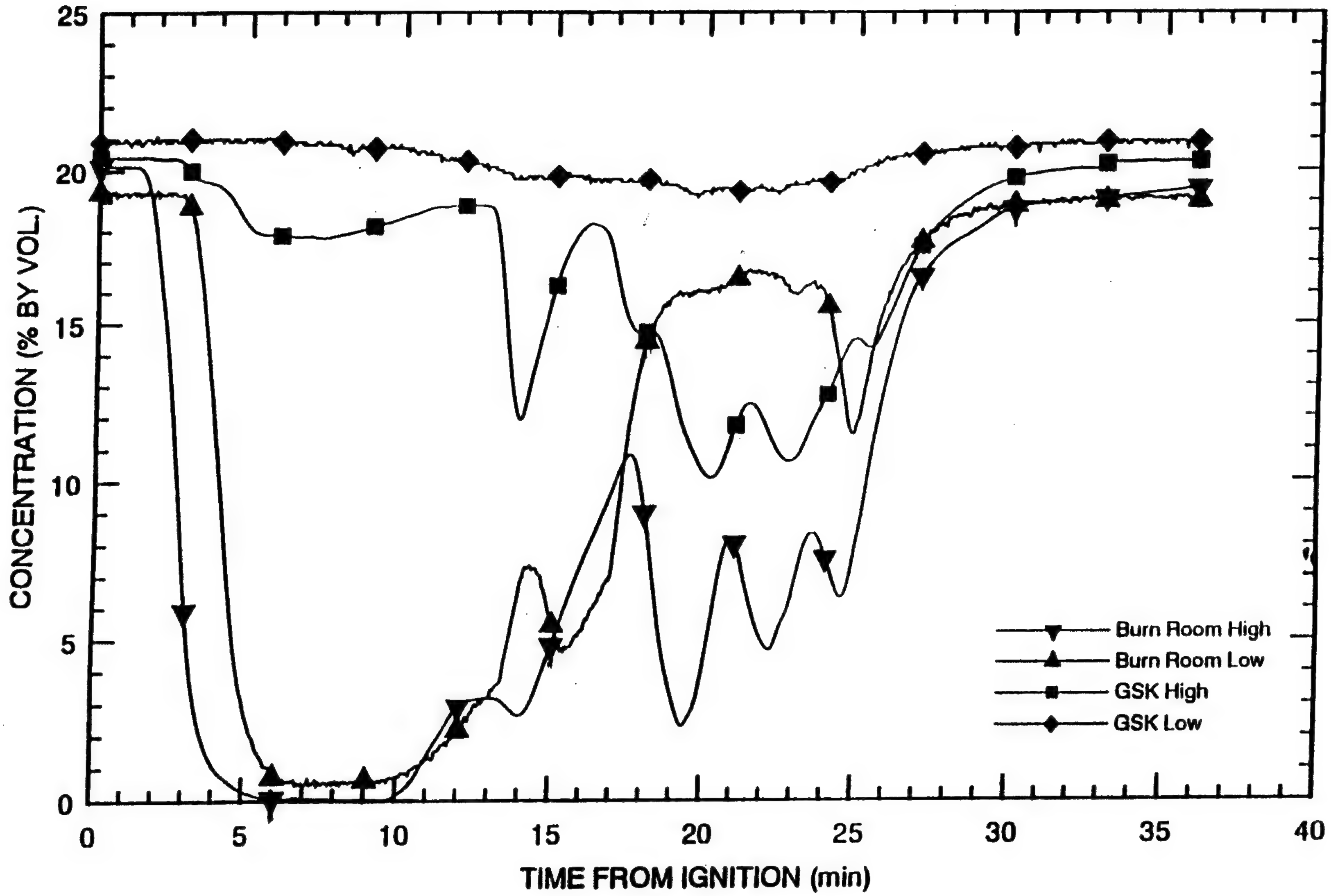


Fig. B64 - Oxygen (O_2) concentrations for FOG_14

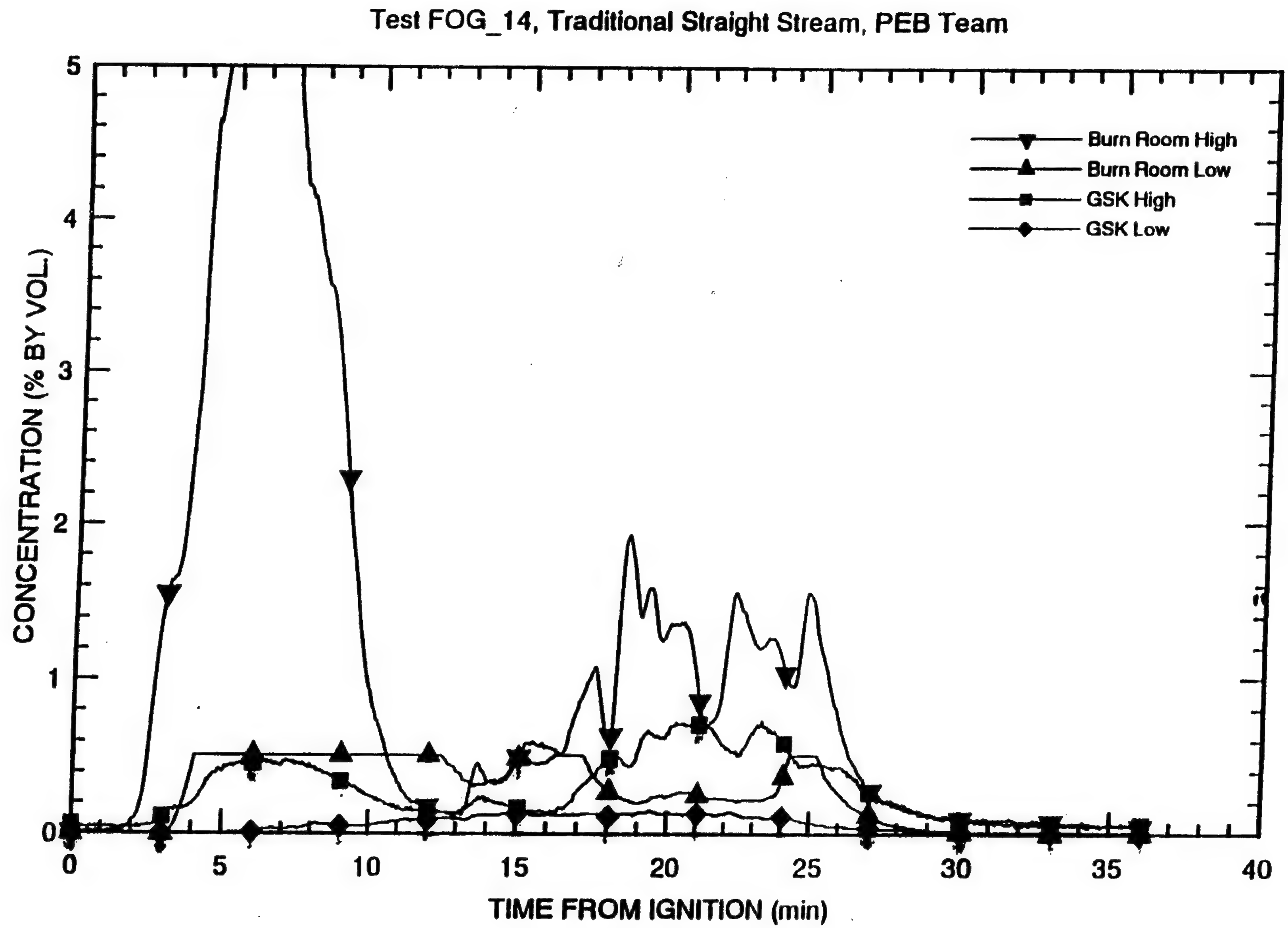


Fig. B65 - Carbon monoxide (CO) concentrations for FOG_14

Test FOG_14, Traditional Straight Stream, PEB Team

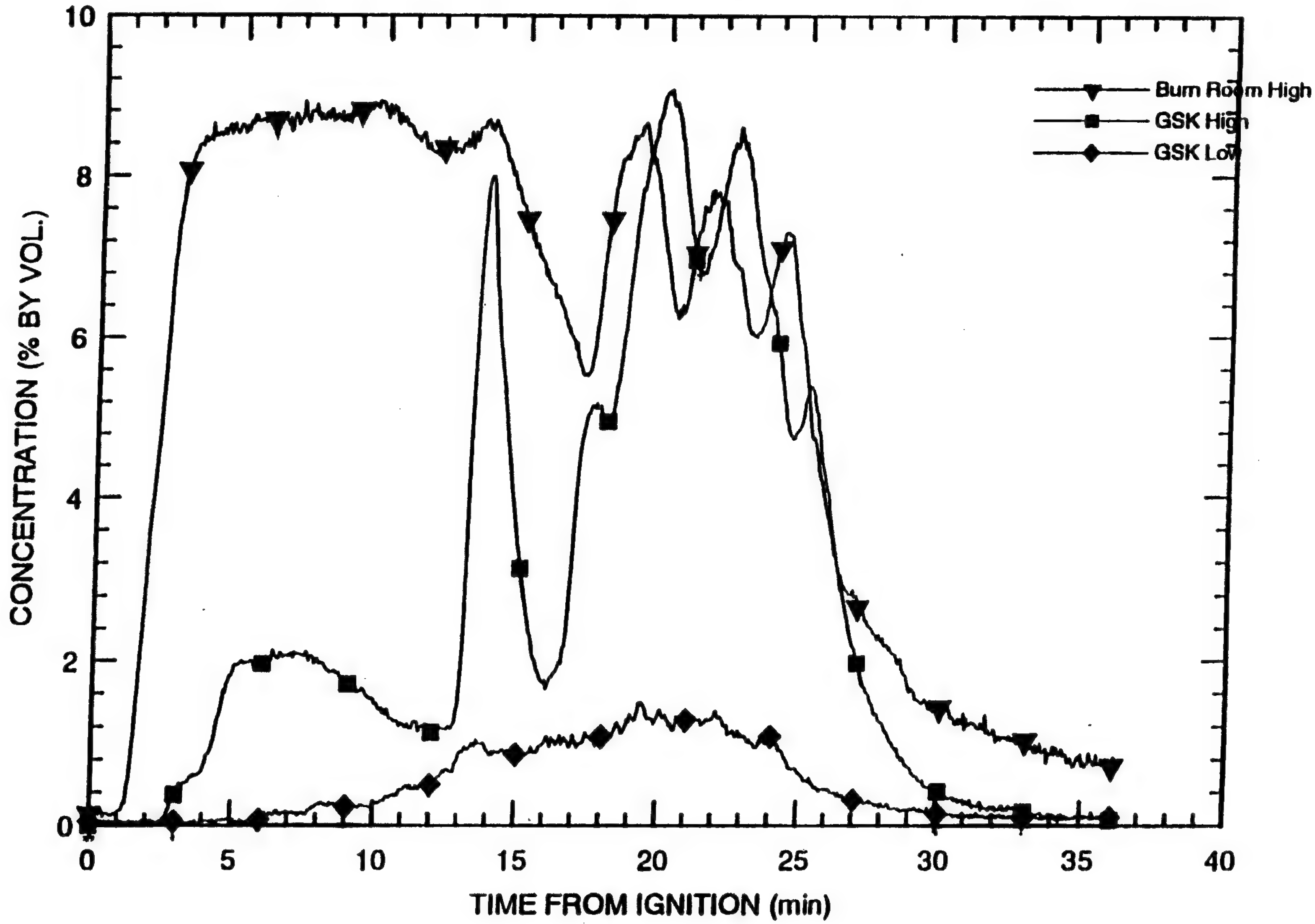


Fig. B66 - Carbon dioxide (CO_2) concentrations for FOG_14

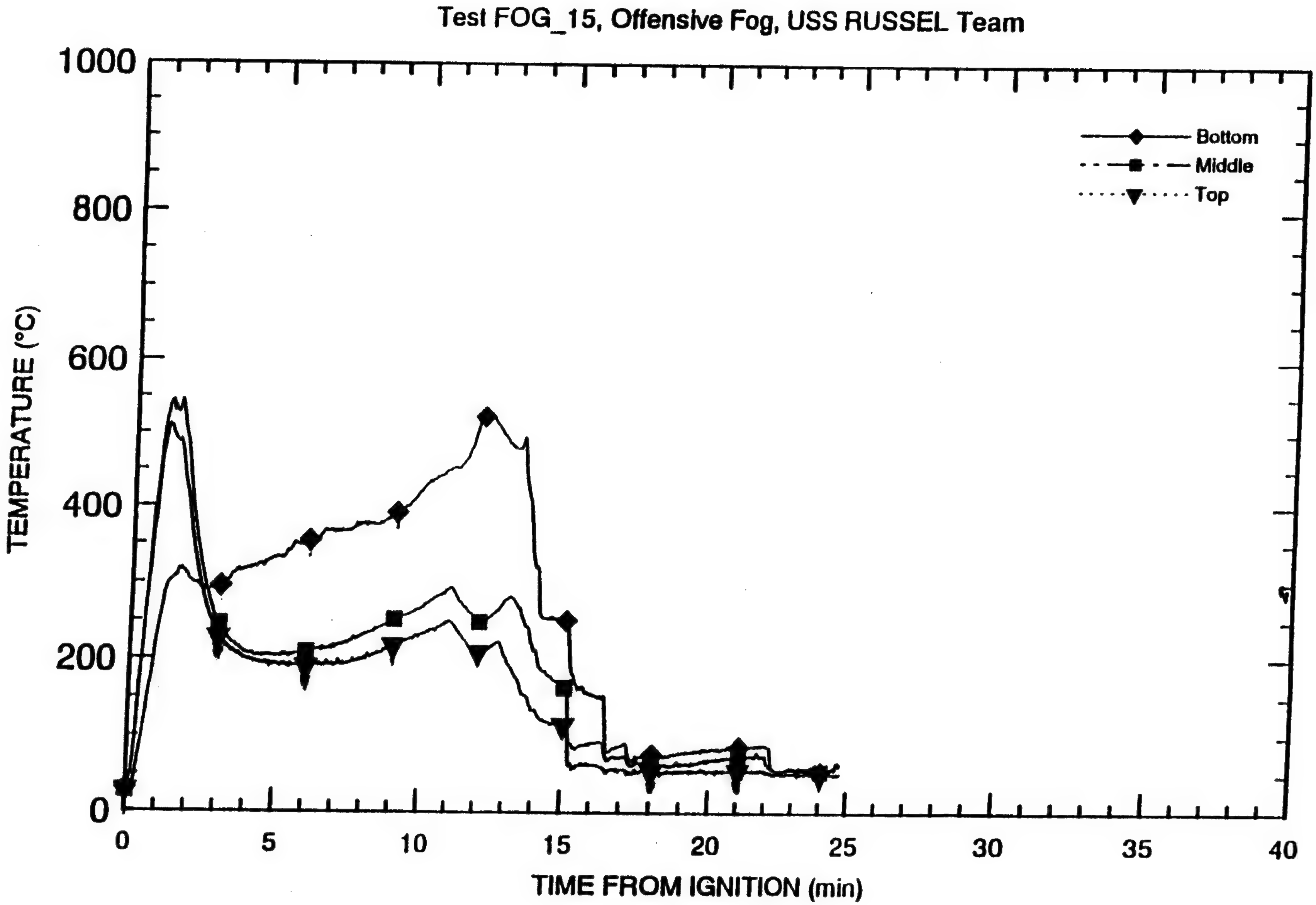


Fig. B67 - Wood crib #1 thermocouples for FOG_15

Test FOG_15, Offensive Fog, USS RUSSEL Team

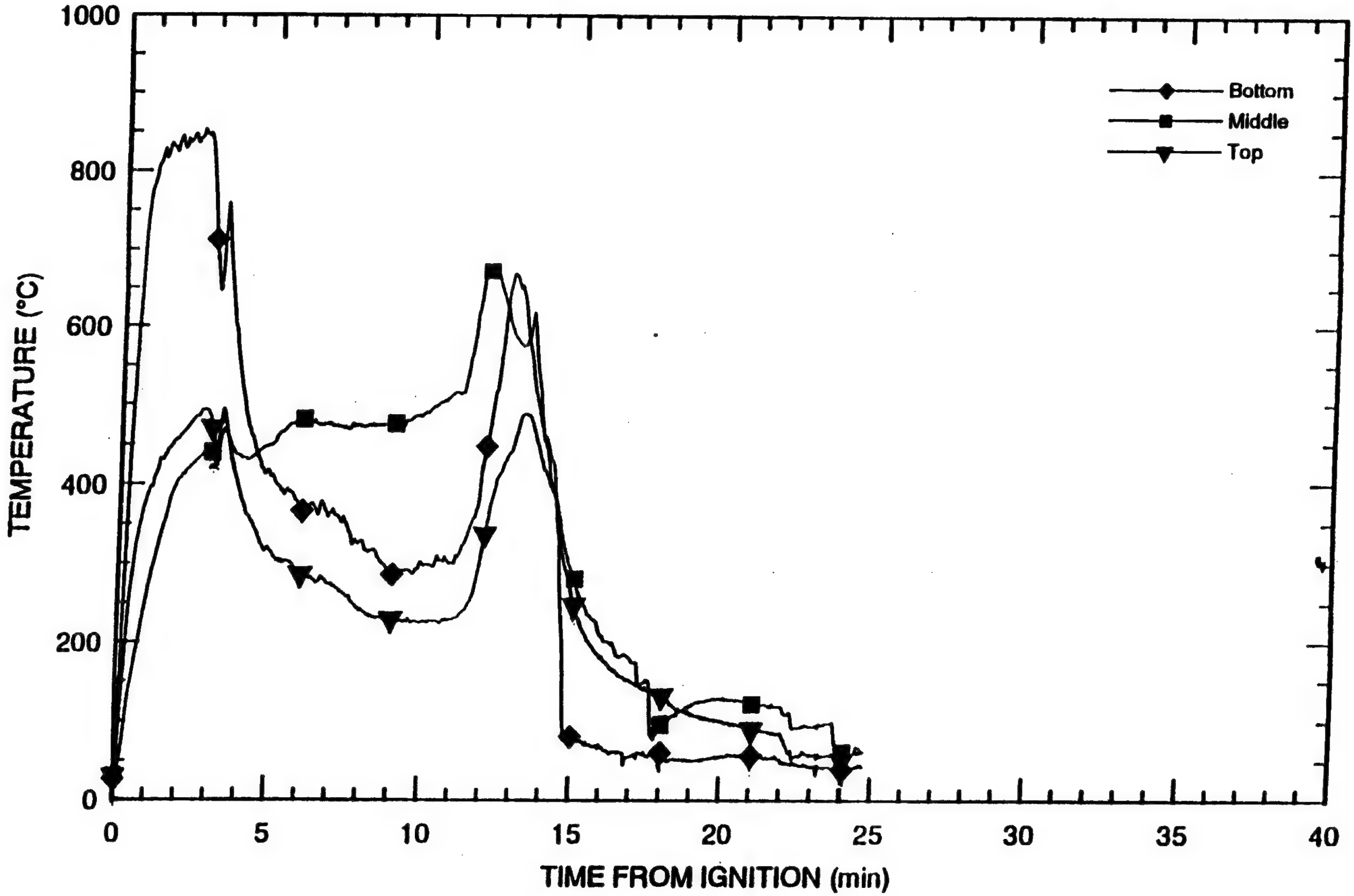


Fig. B68 - Wood crib #2 thermocouples for FOG_15

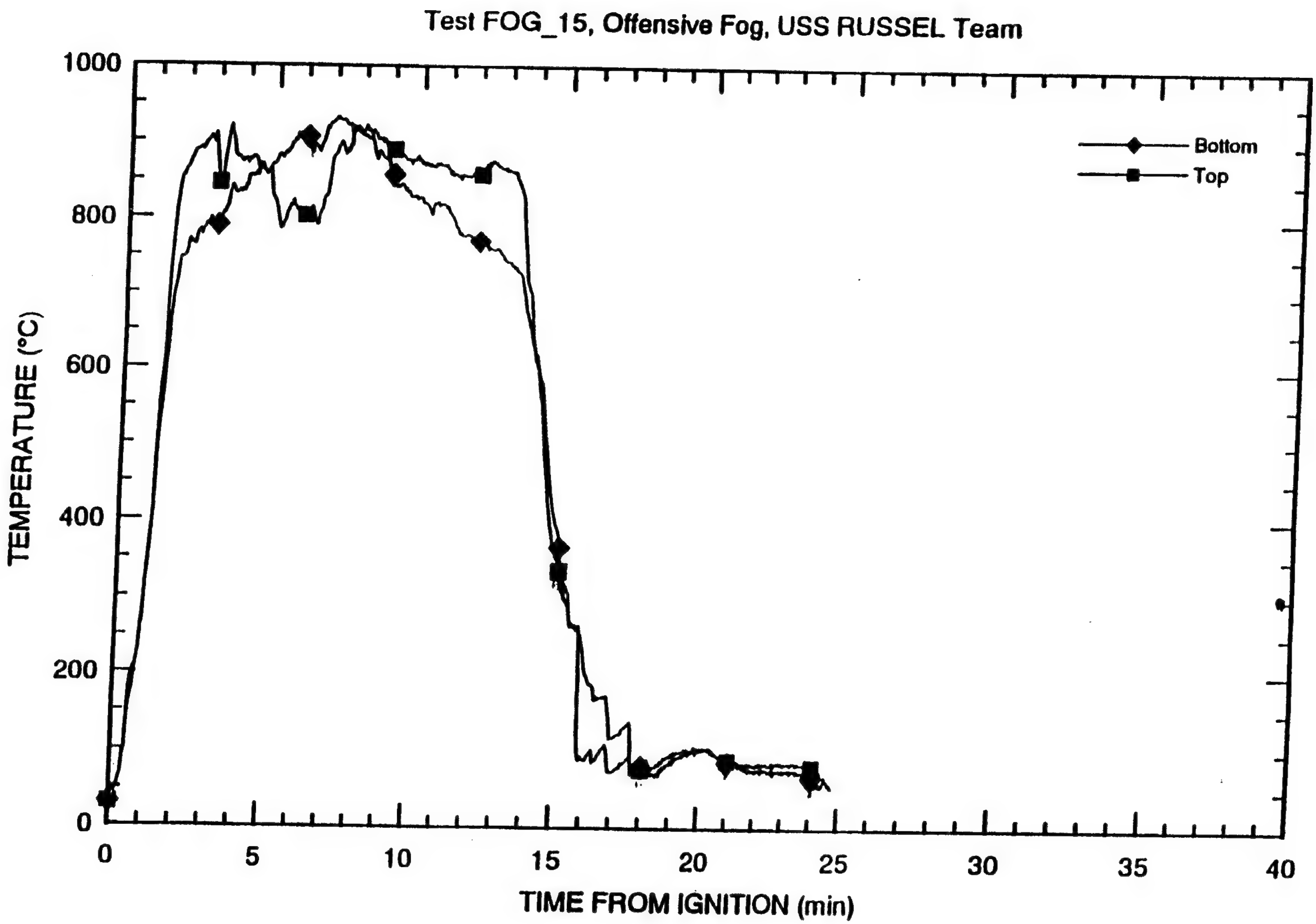


Fig. B69 - Wood crib #3 thermocouples for FOG_15

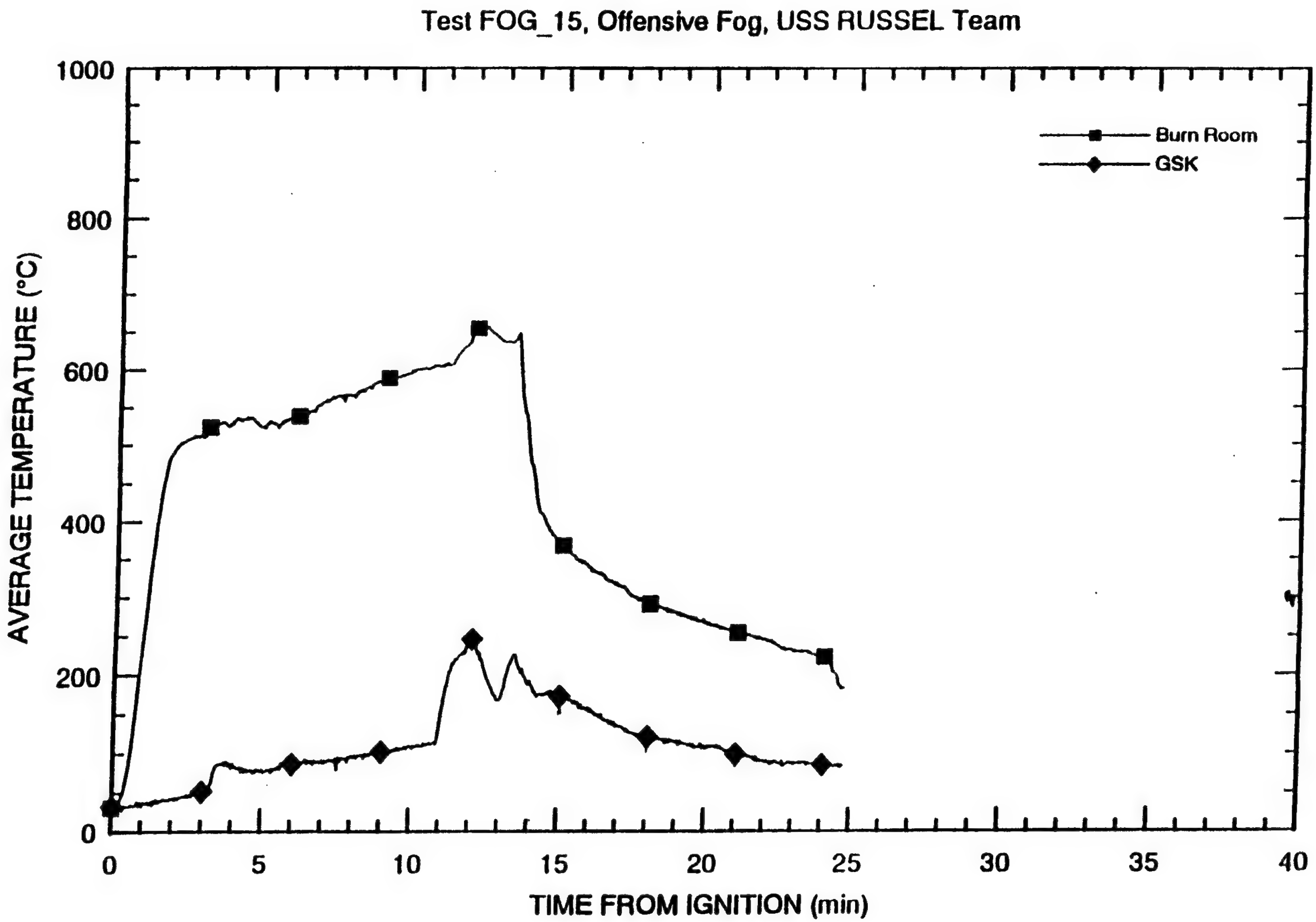


Fig. B70 - Average of overhead thermocouples for FOG_15

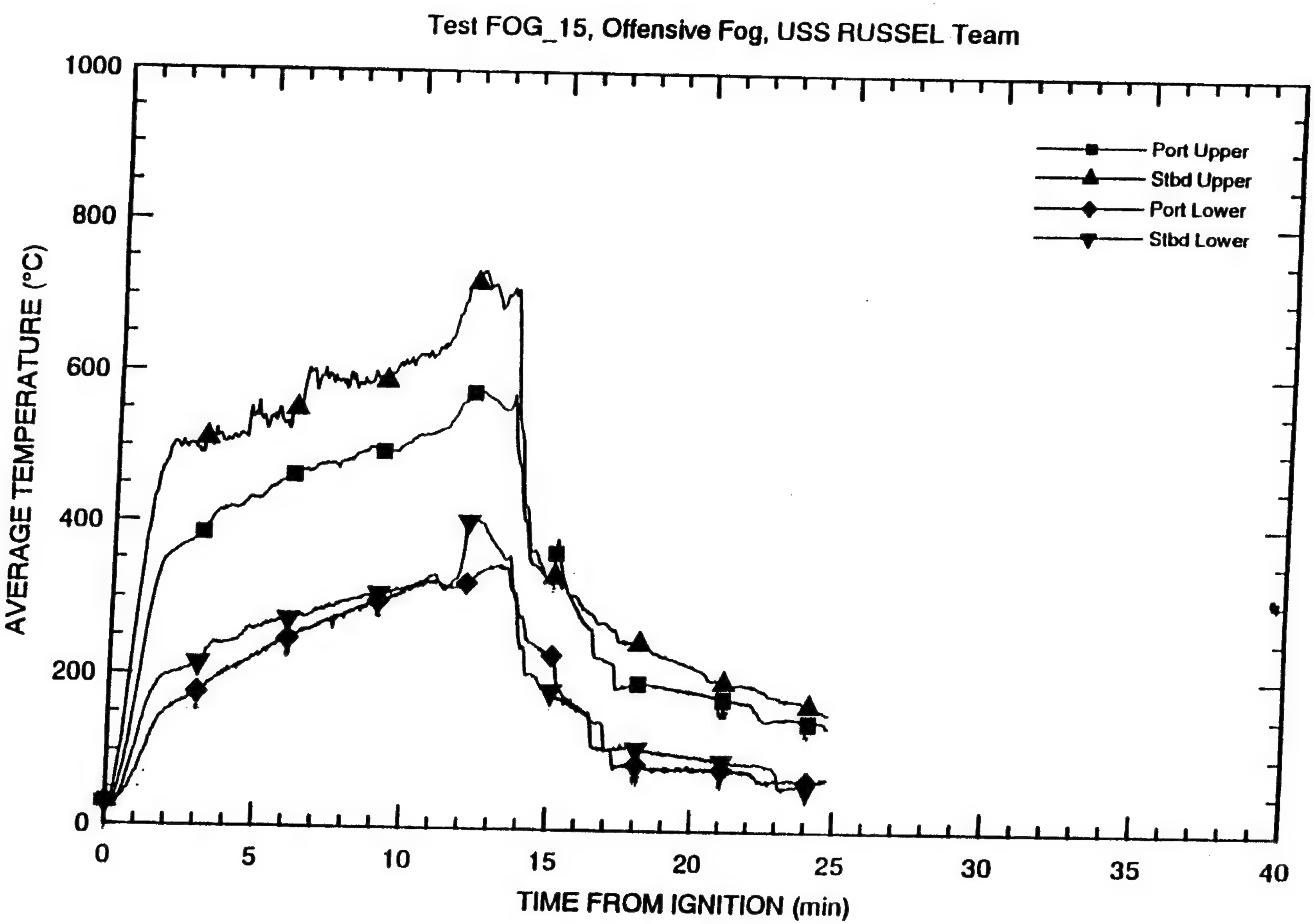


Fig. B71 - Burn room thermocouple string averages (upper vs. lower) for FOG_15

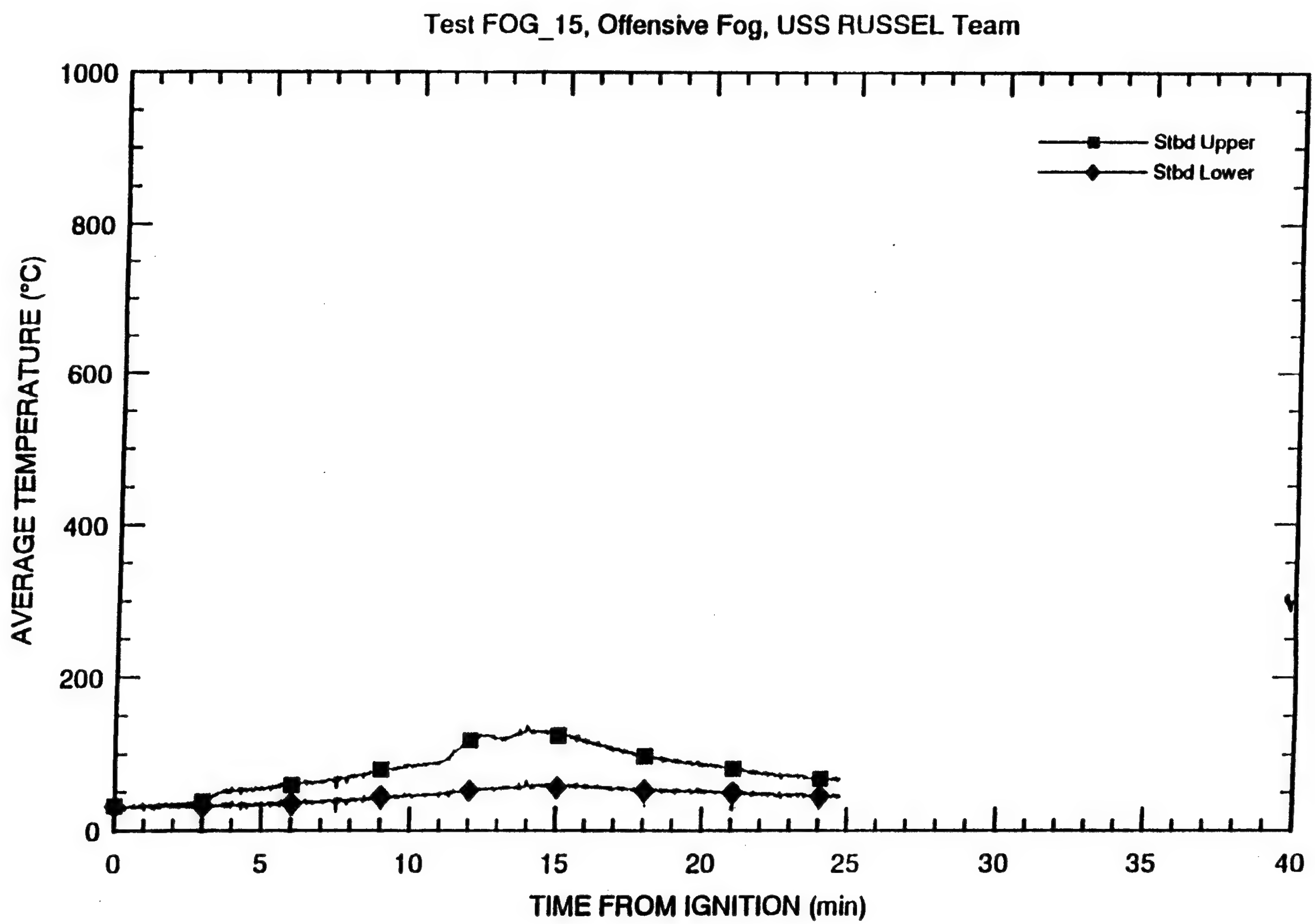


Fig. B72 - GSK thermocouple string averages (upper vs. lower) for FOG_15

Test FOG_15, Offensive Fog, USS RUSSEL Team

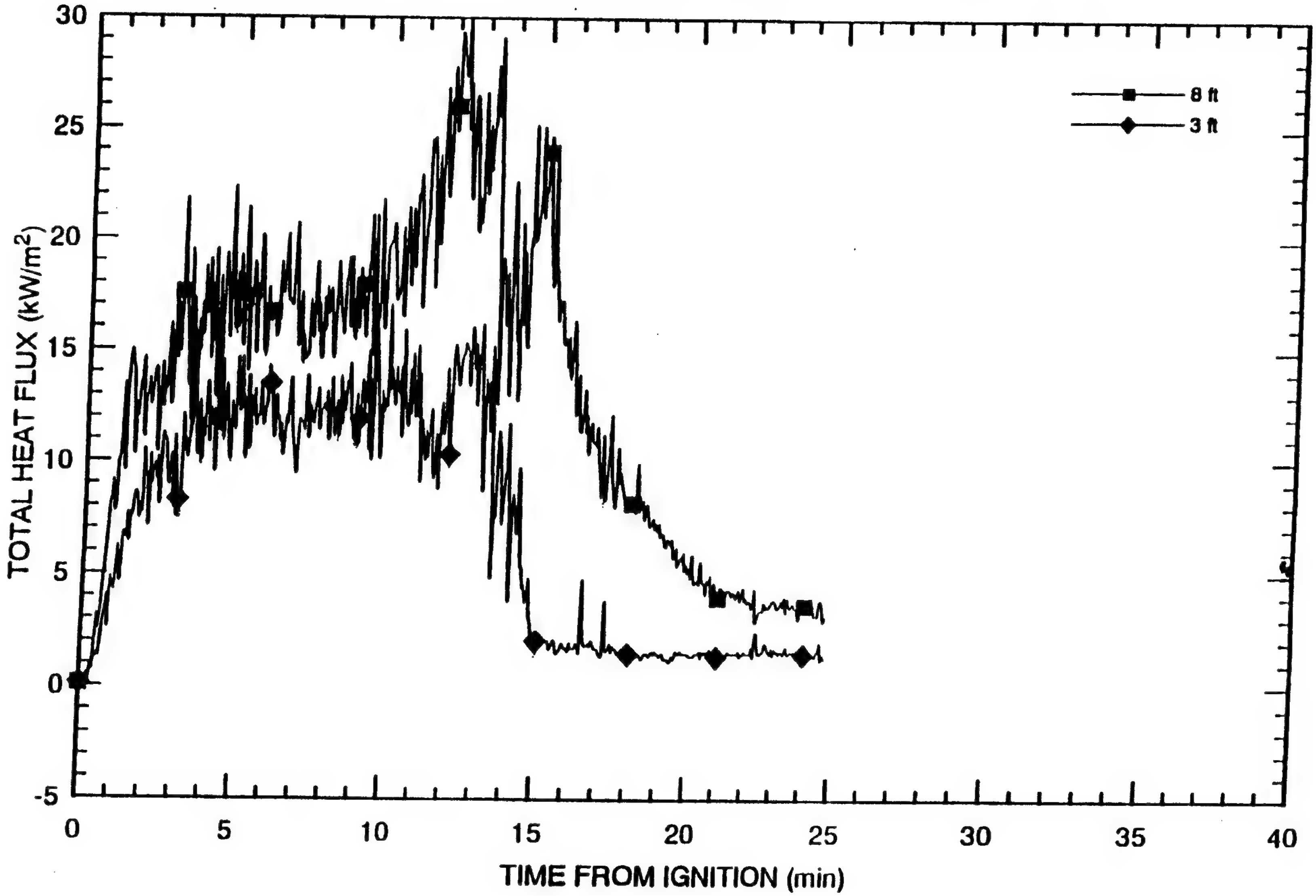


Fig. B73 - Burn room calorimeters for FOG_15

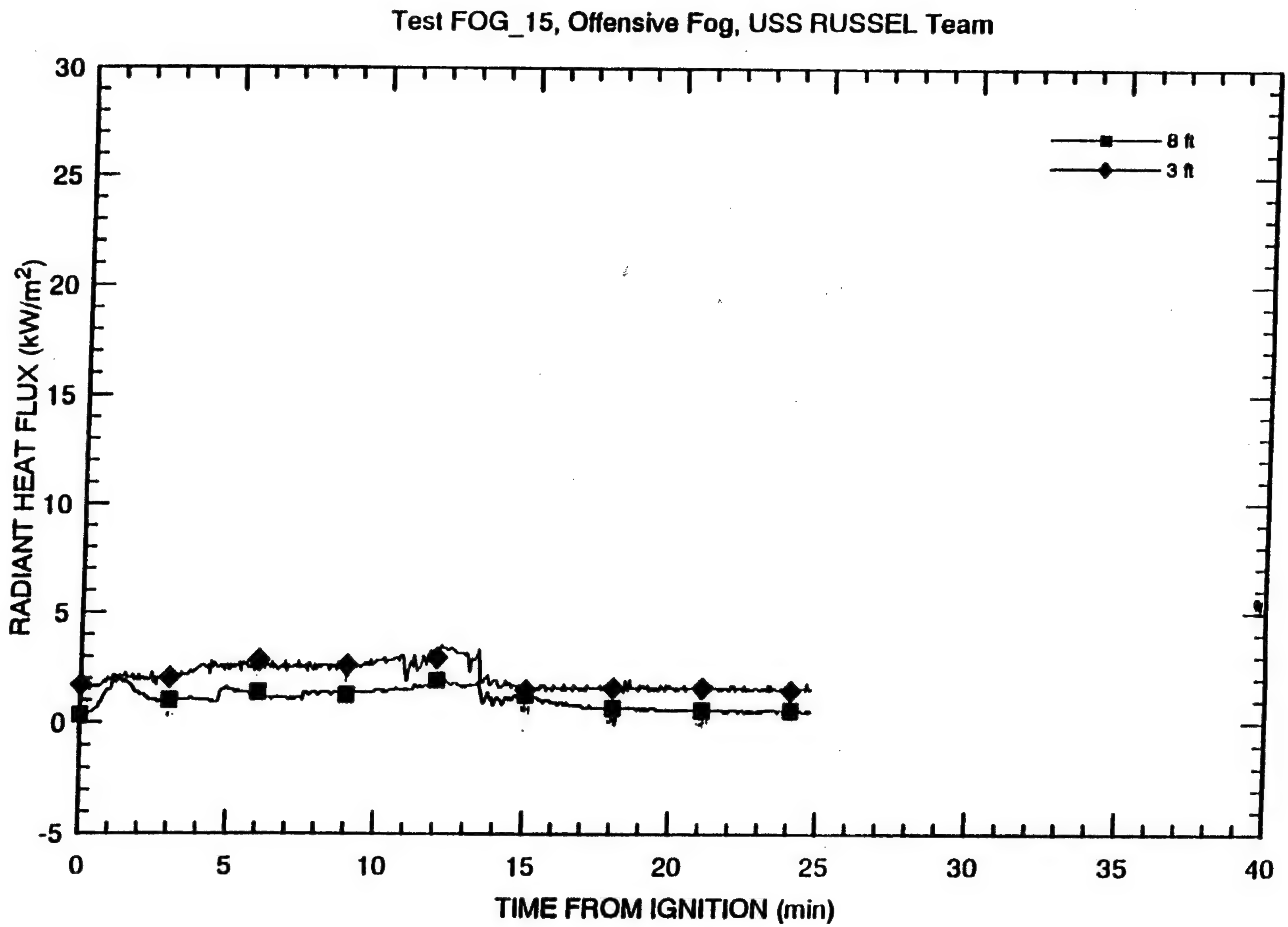


Fig. B74 - Burn room radiometers for FOG_15

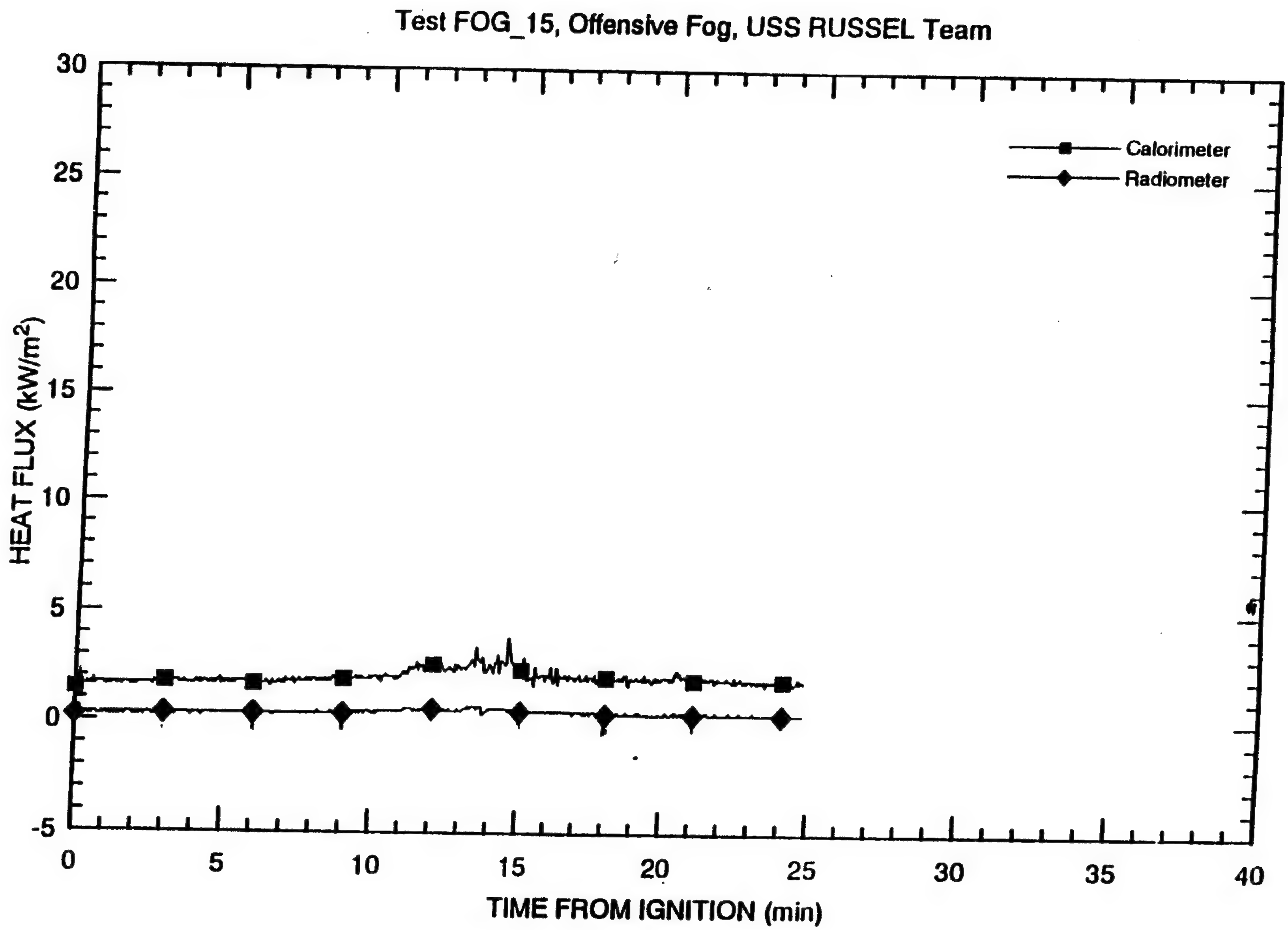


Fig. B75 - GSK radiometer and calorimeter for FOG_15

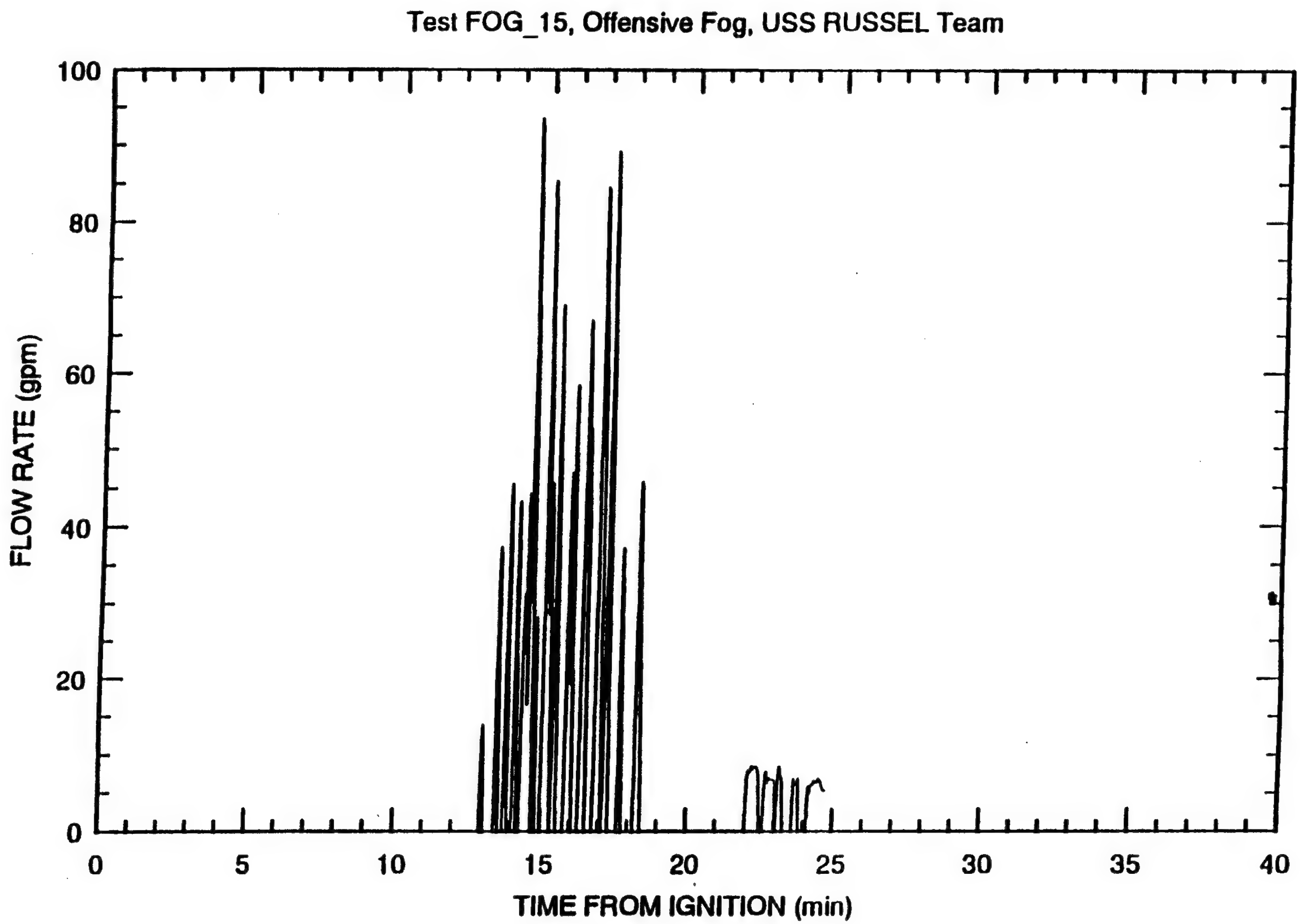


Fig. B76 - Water flow rate for FOG_15

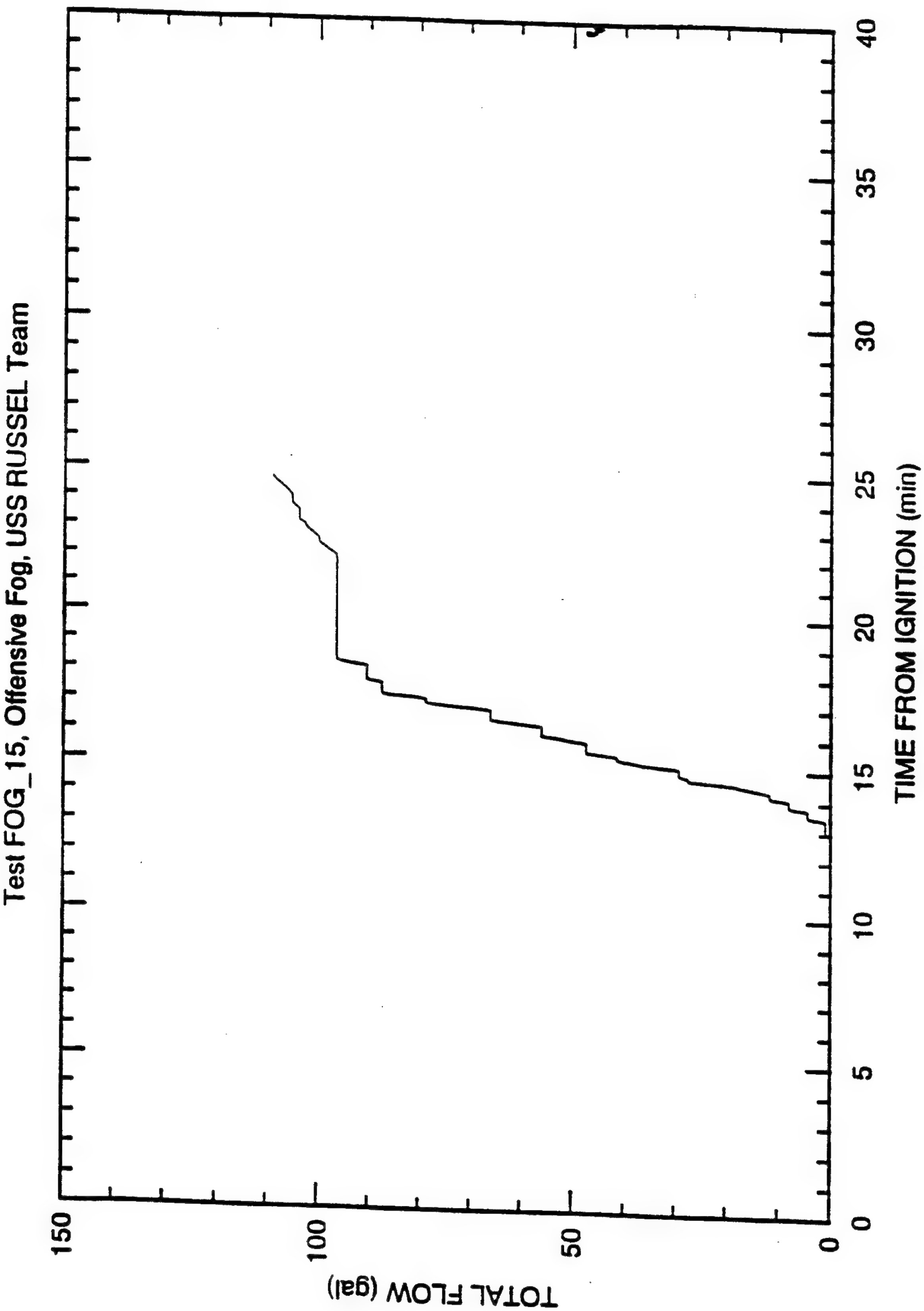


Fig. B77 - Cumulative water flow for FOG_15

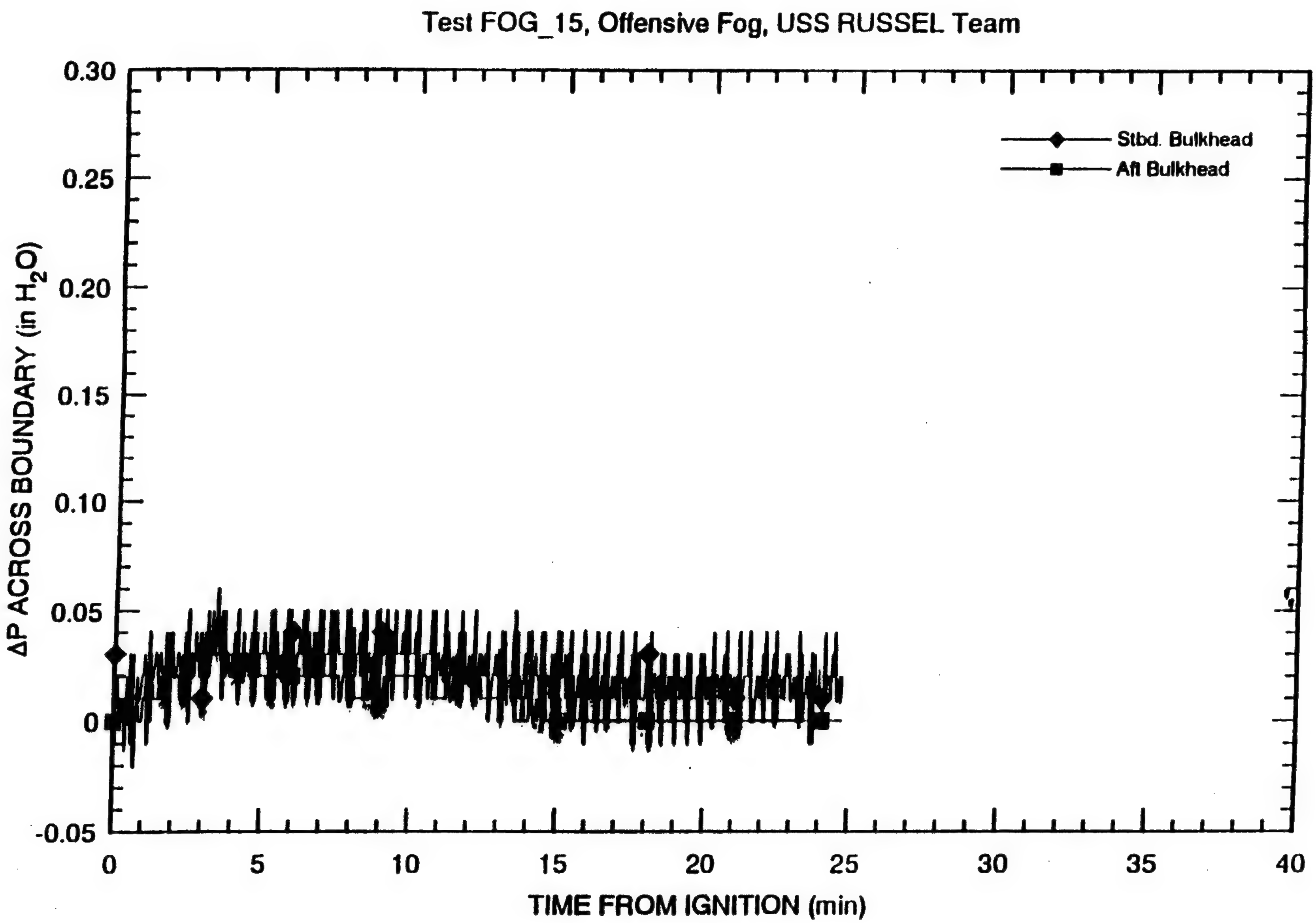


Fig. B78 - Pressure differential across burn room boundaries for FOG_15

Test FOG_15, Offensive Fog, USS RUSSEL Team

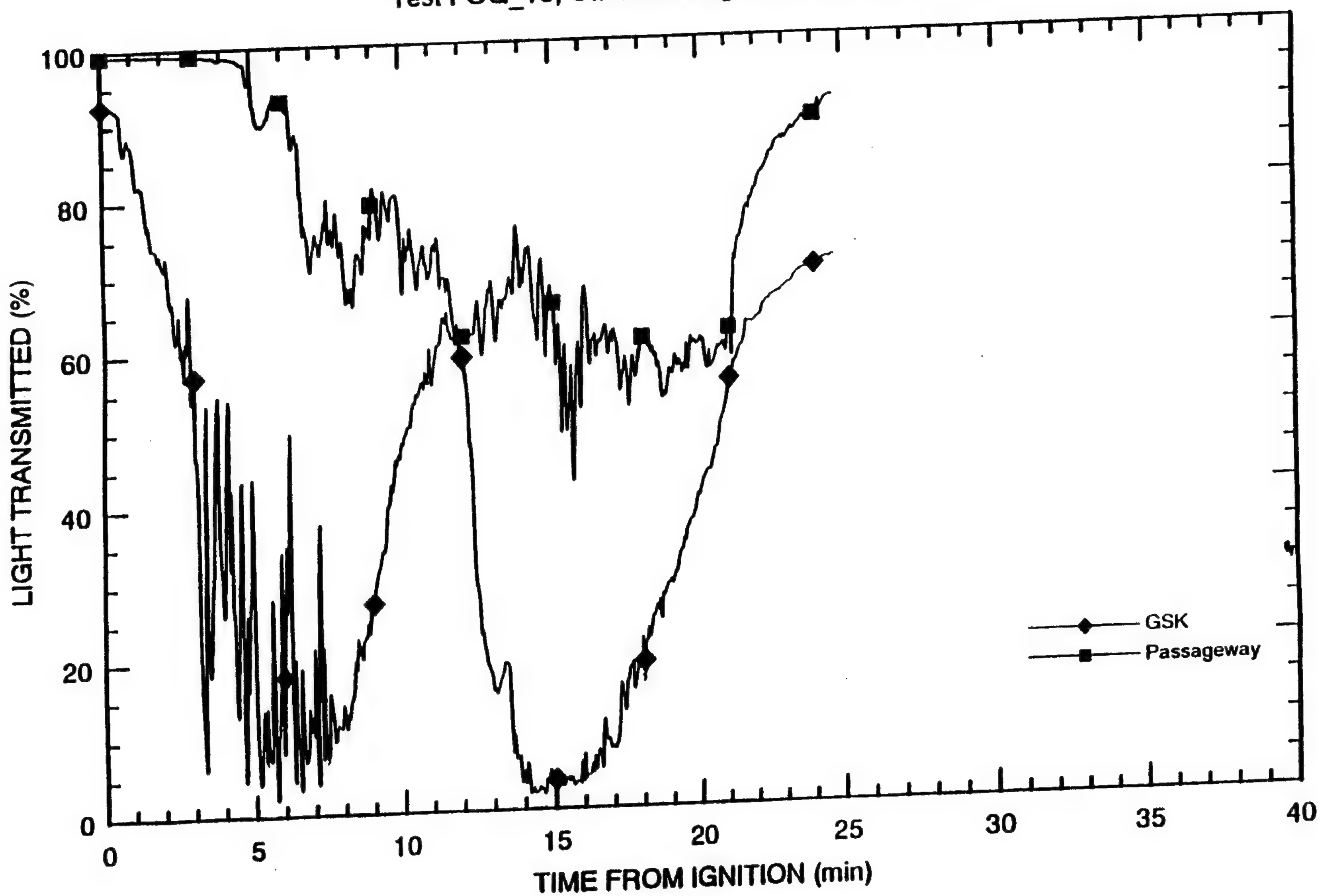


Fig. B79 - Smoke Obscuration for FOG_15

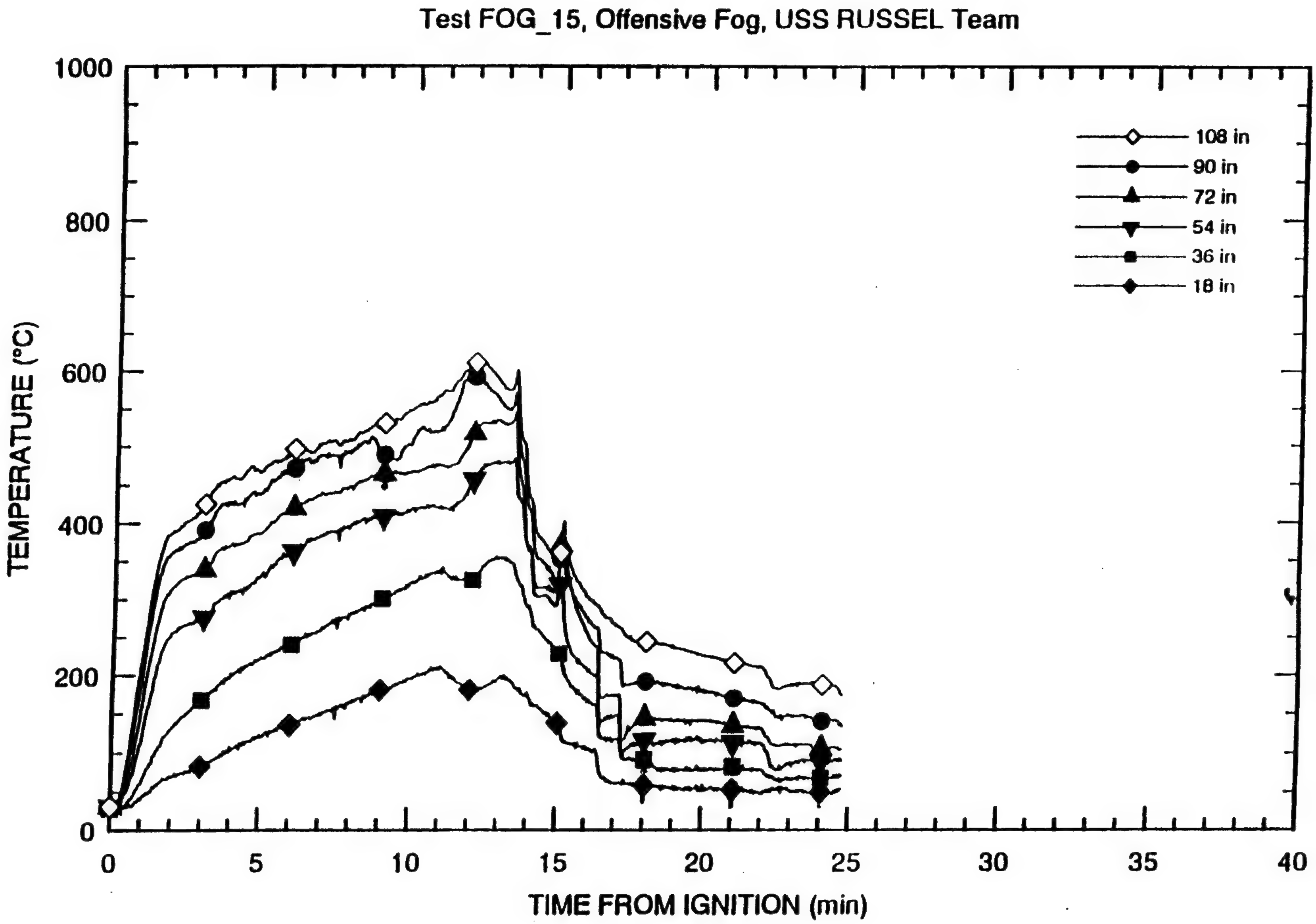


Fig. B80 - Port outer (2-18-2) thermocouple tree for FOG_15

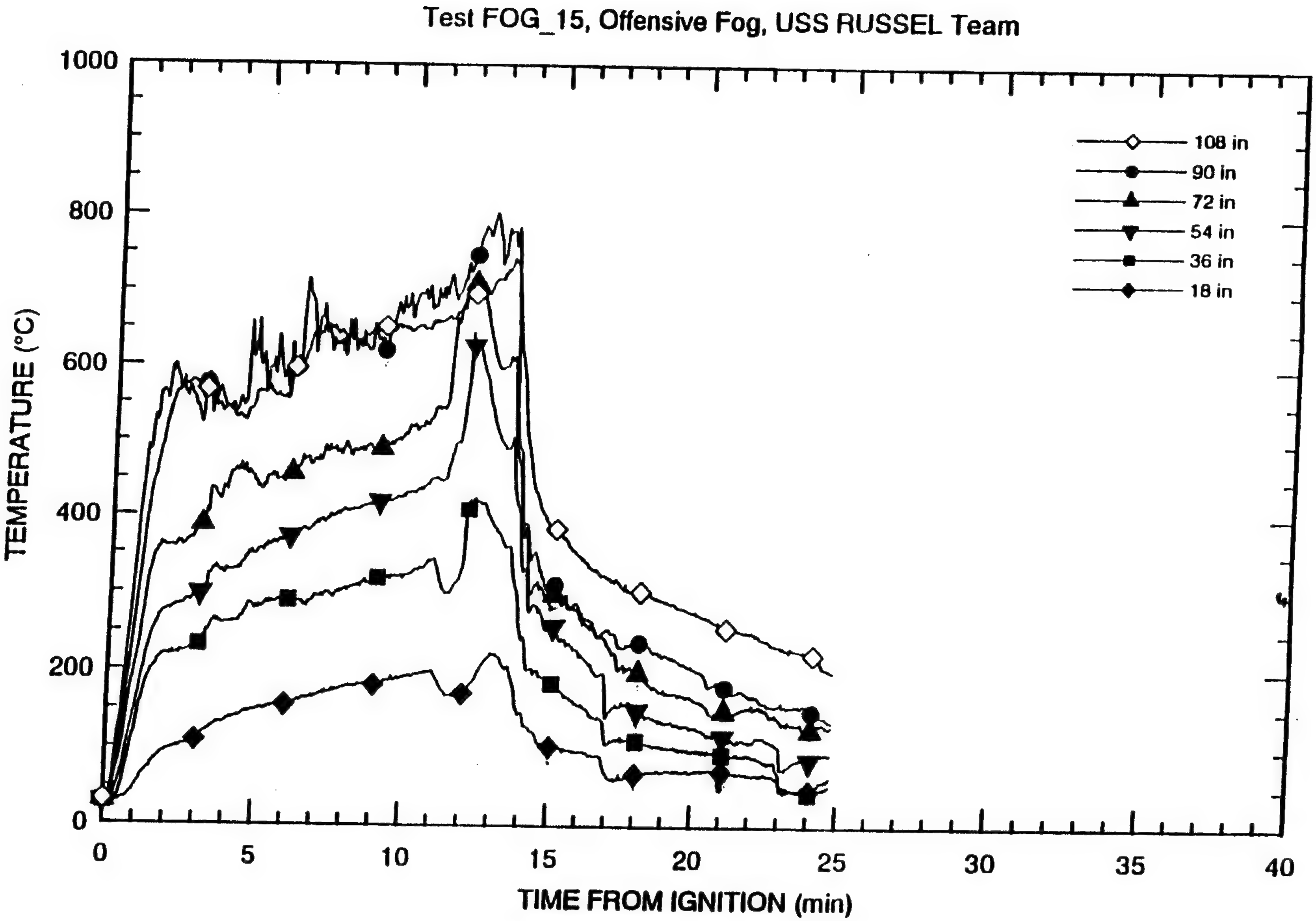


Fig. B81 - Port inner (2-19-0) thermocouple tree for FOG_15

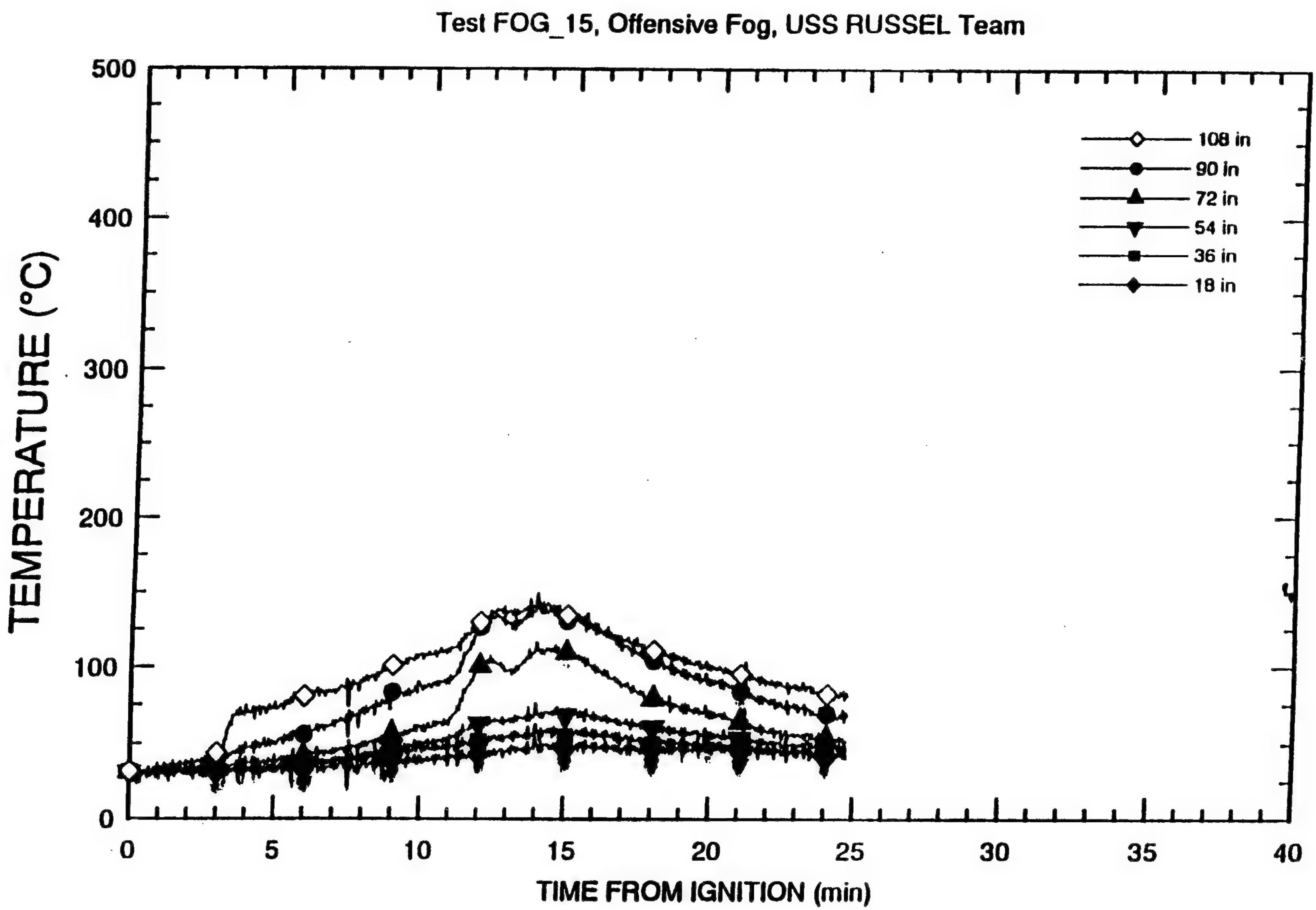


Fig. B82 - Starboard outer (2-21-3) thermocouple tree for FOG_15

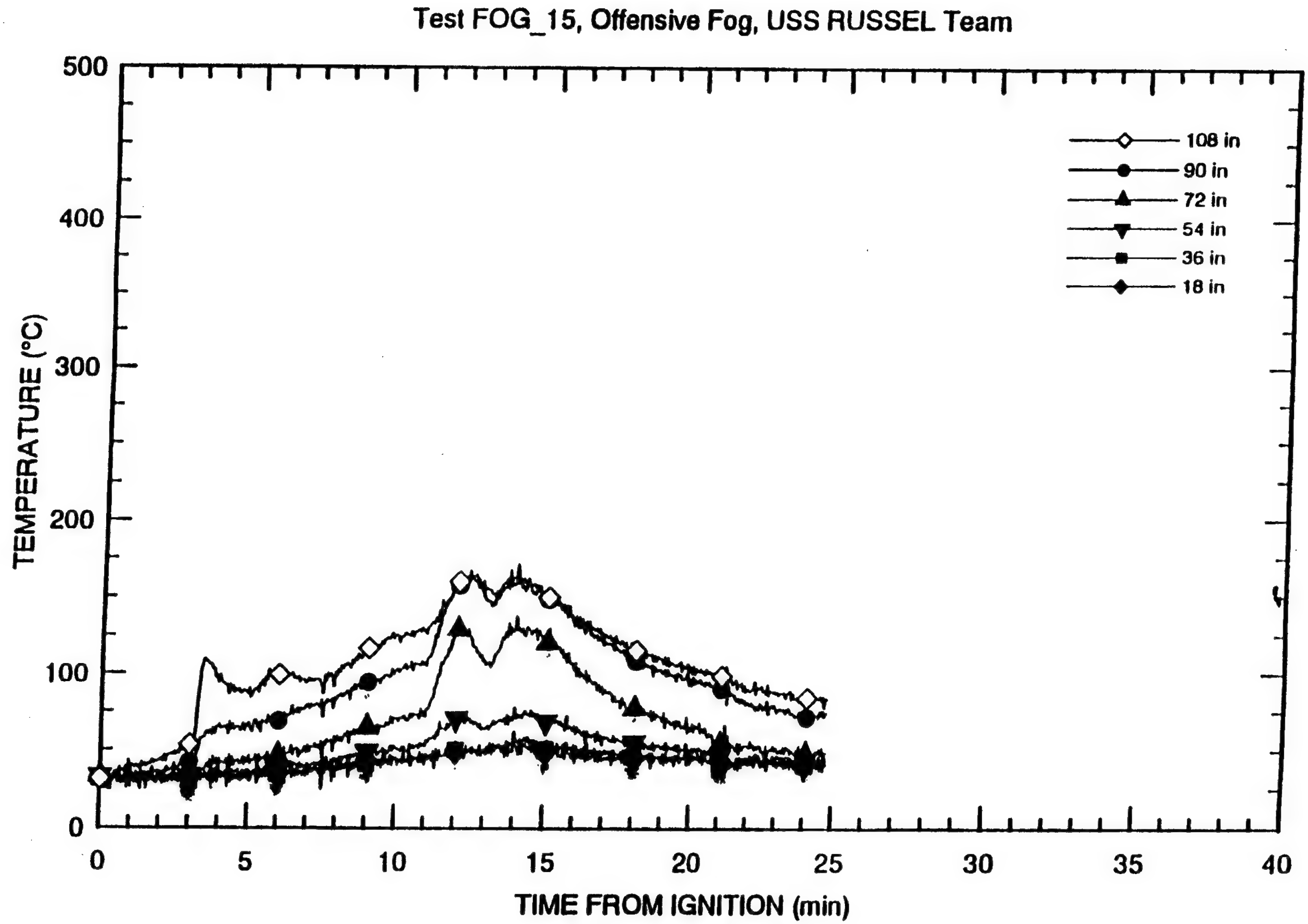


Fig. B83 - Starboard inner (2-21-1) thermocouple tree for FOG_15

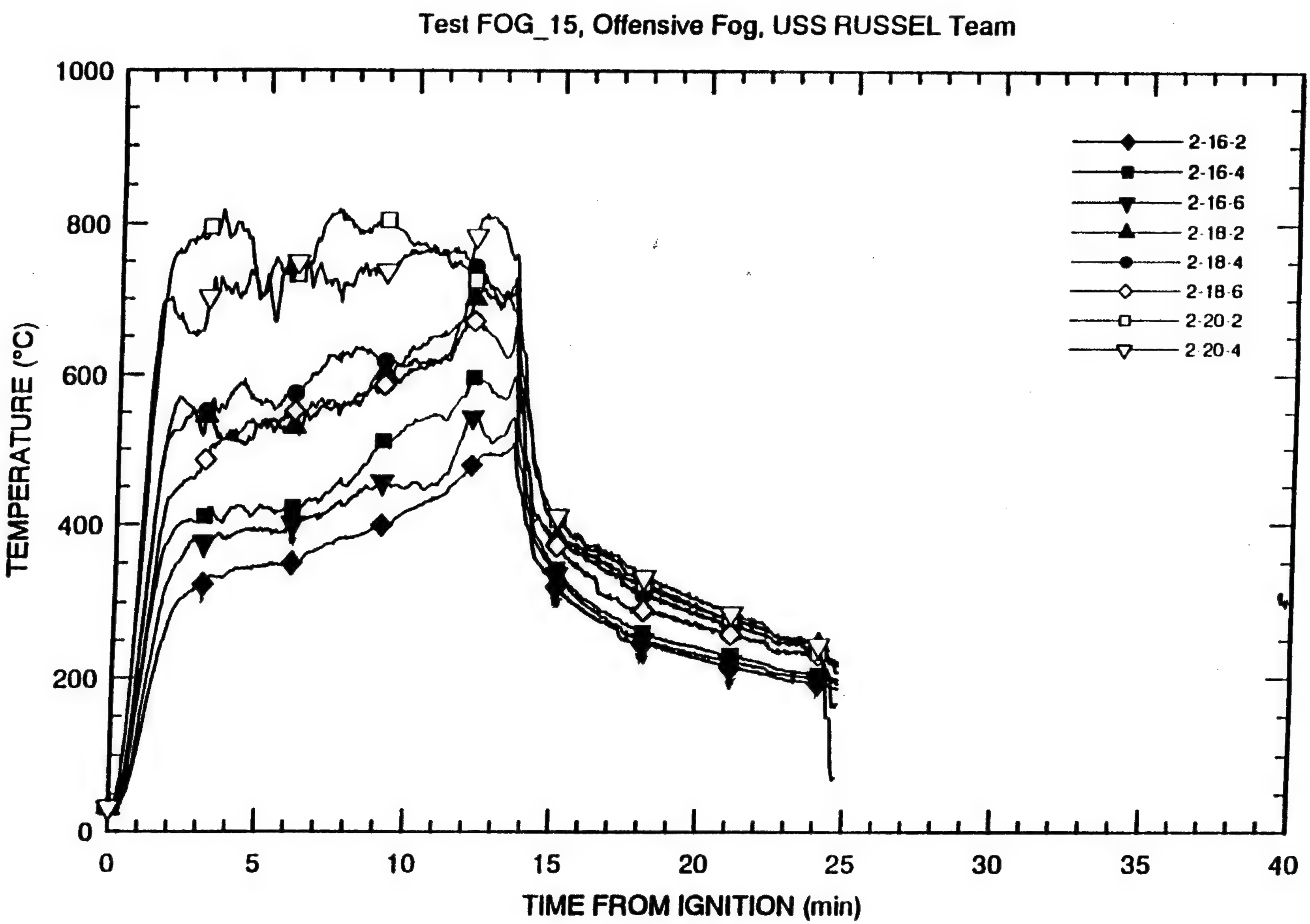


Fig. B84 - Burn room overhead temperatures for FOG_15

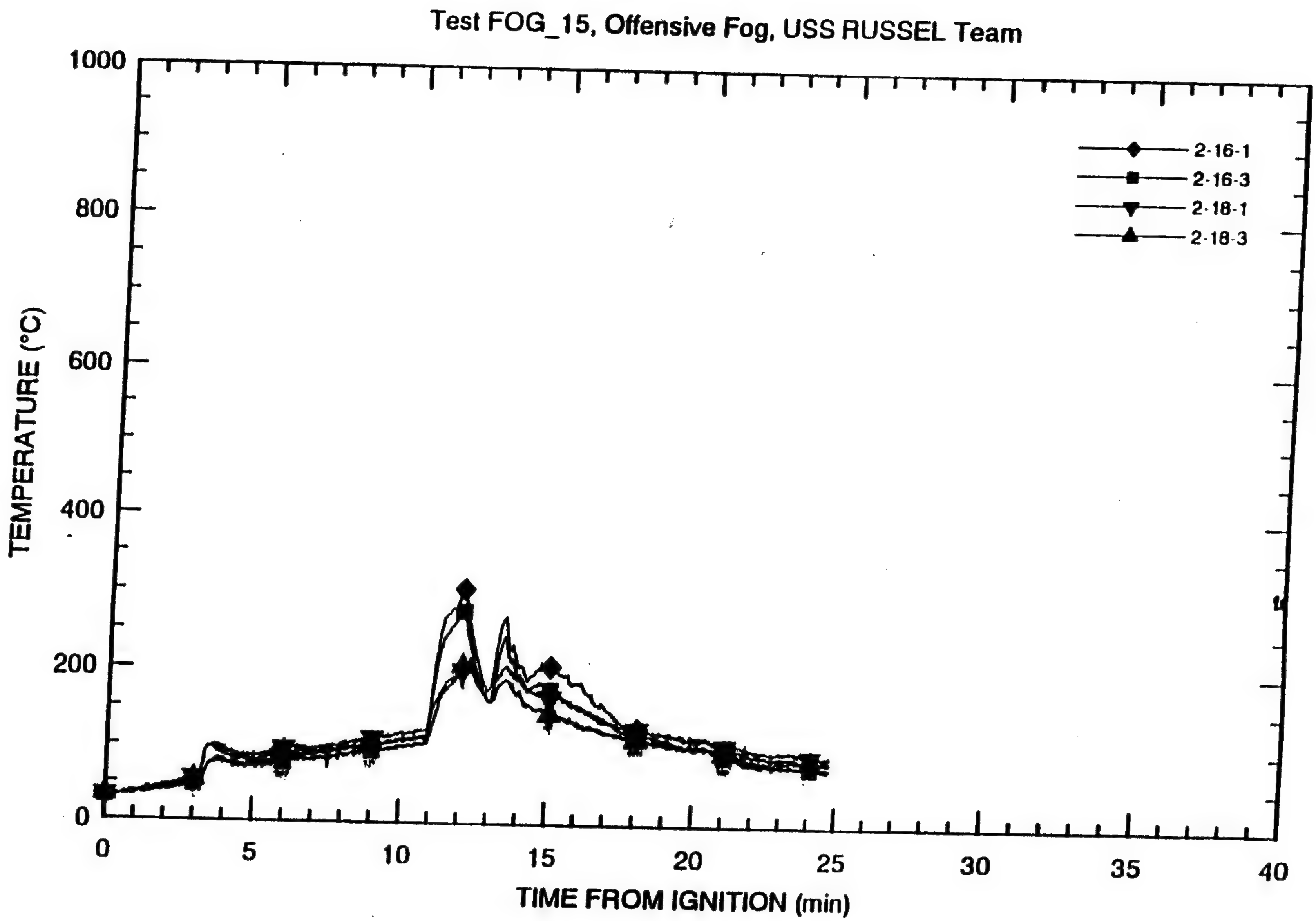


Fig. B85 - GSK overhead temperatures for FOG_15

Test FOG_15, Offensive Fog, USS RUSSEL Team

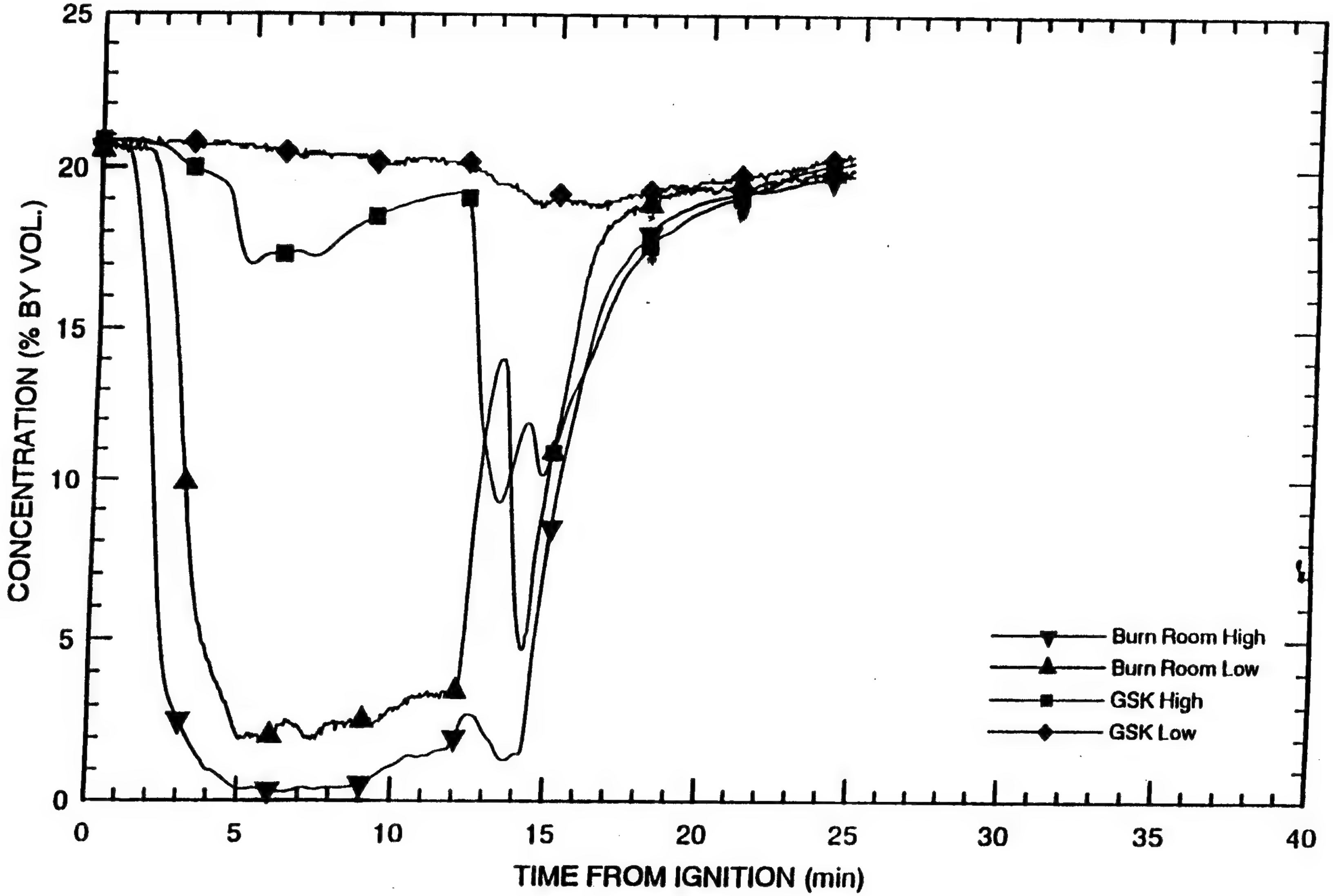


Fig. B86 - Oxygen (O_2) concentrations for FOG_15

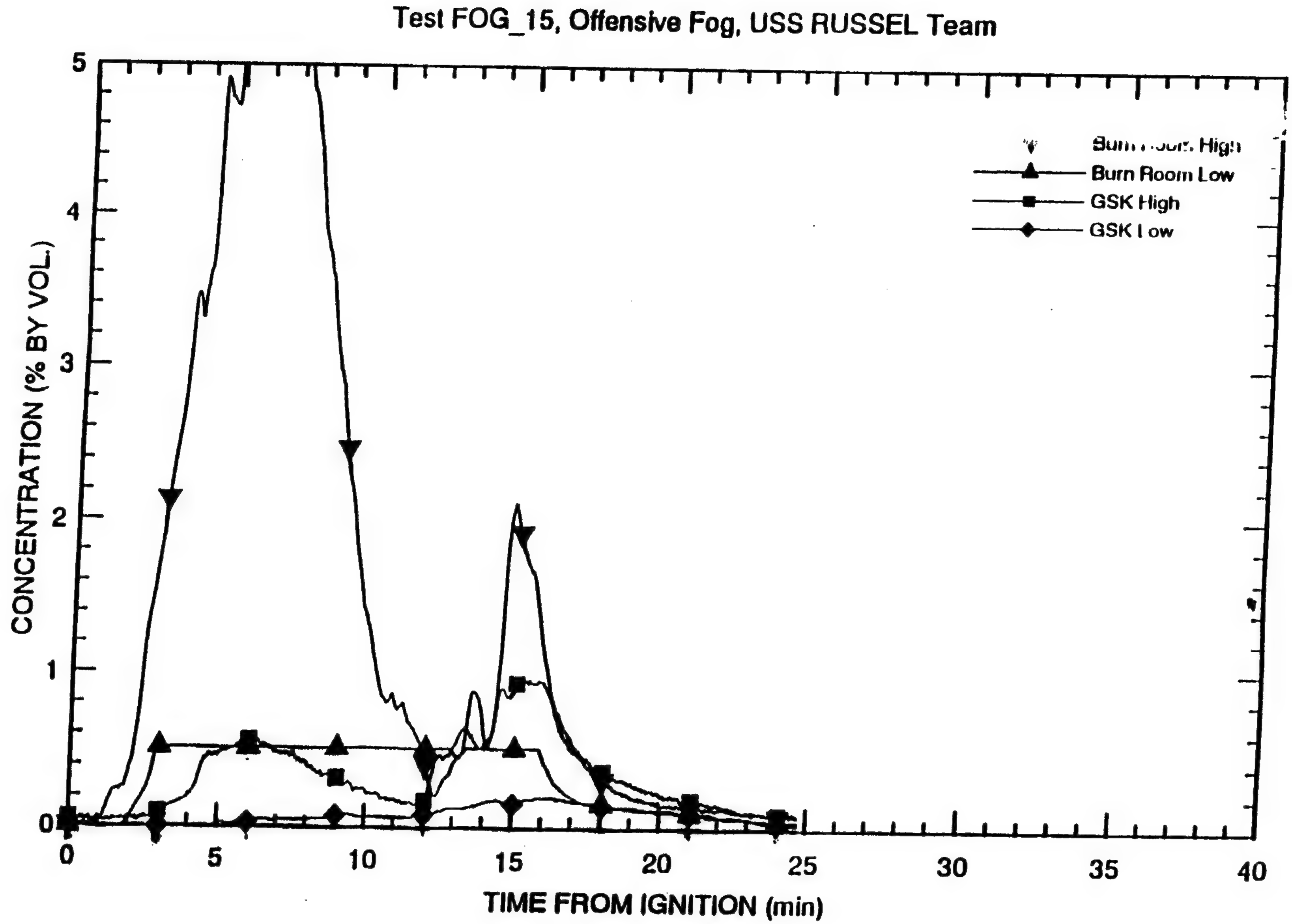


Fig. B87 - Carbon monoxide (CO) concentrations for FOG_15

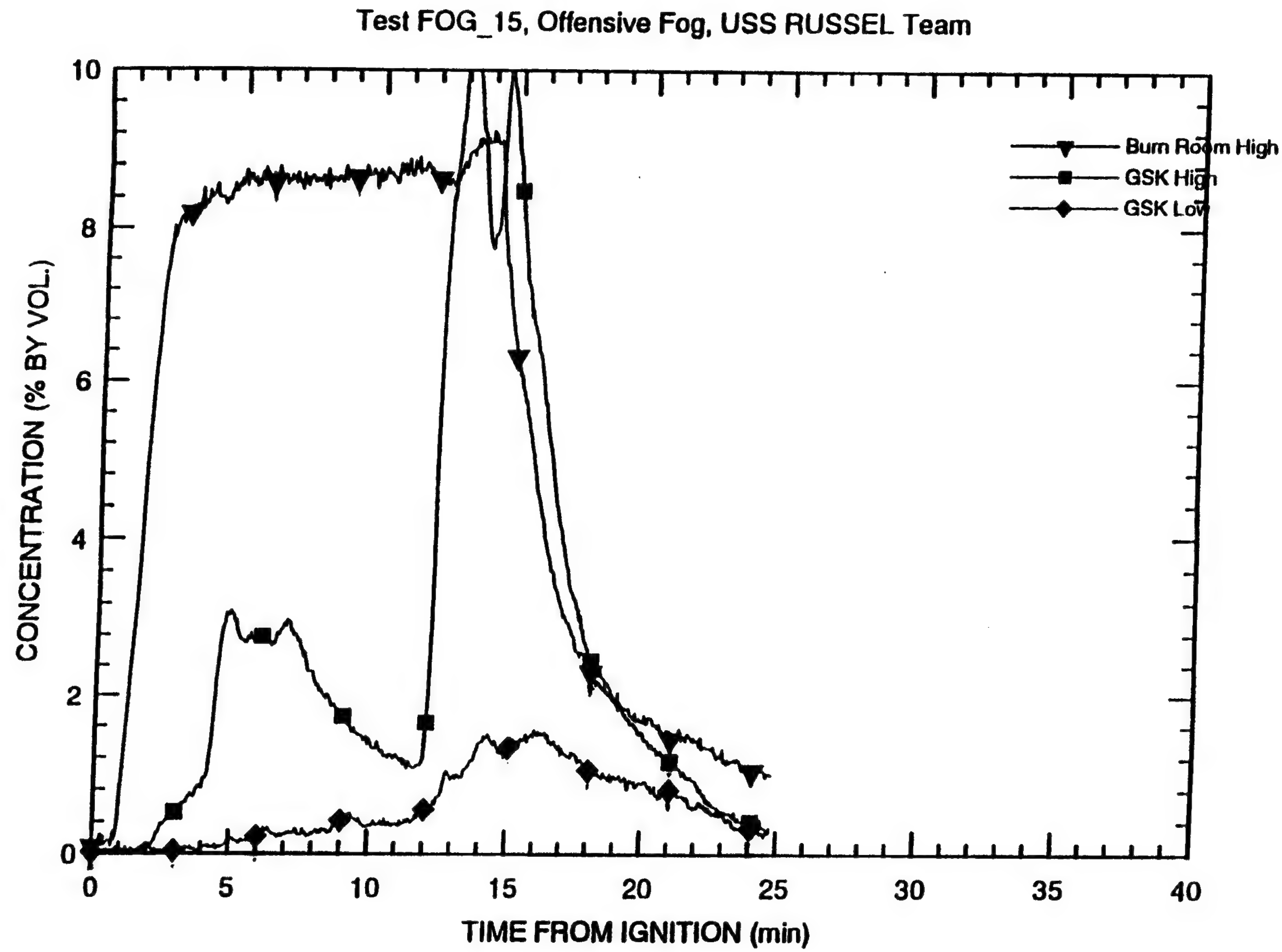


Fig. B88 - Carbon dioxide (CO_2) concentrations for FOG_15

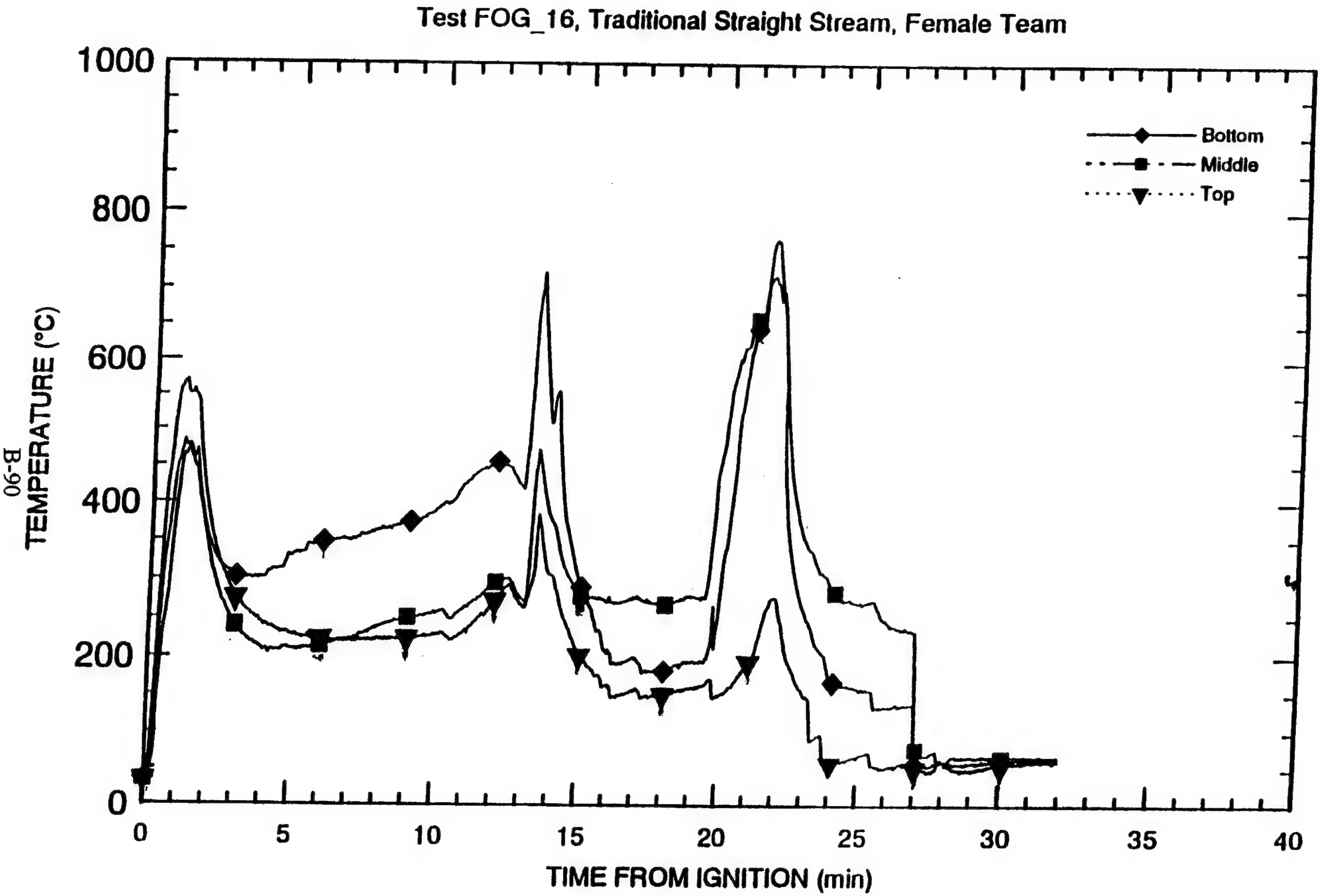


Fig. B89 - Wood crib #1 thermocouples for FOG_16

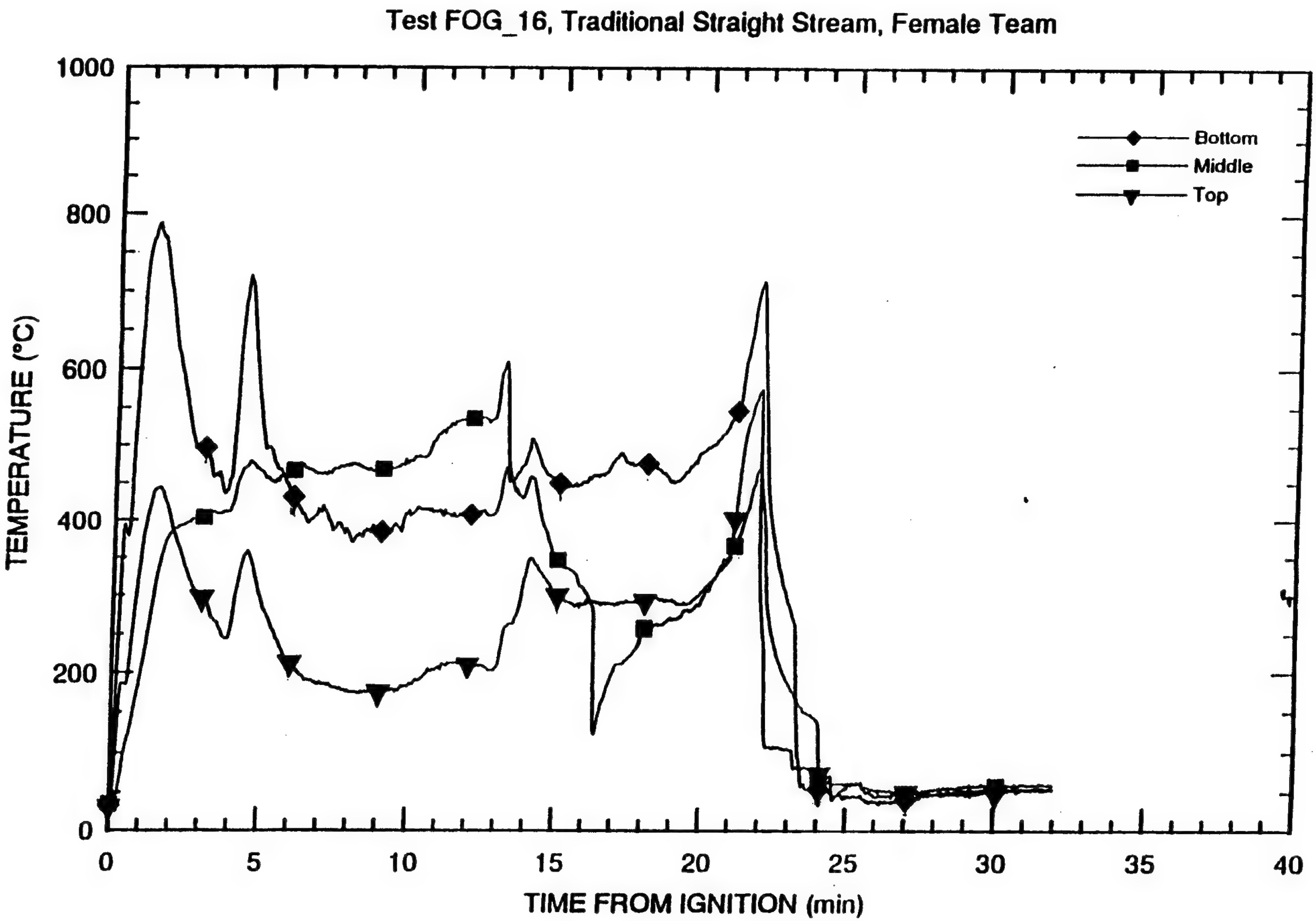


Fig. B90 - Wood crib #2 thermocouples for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

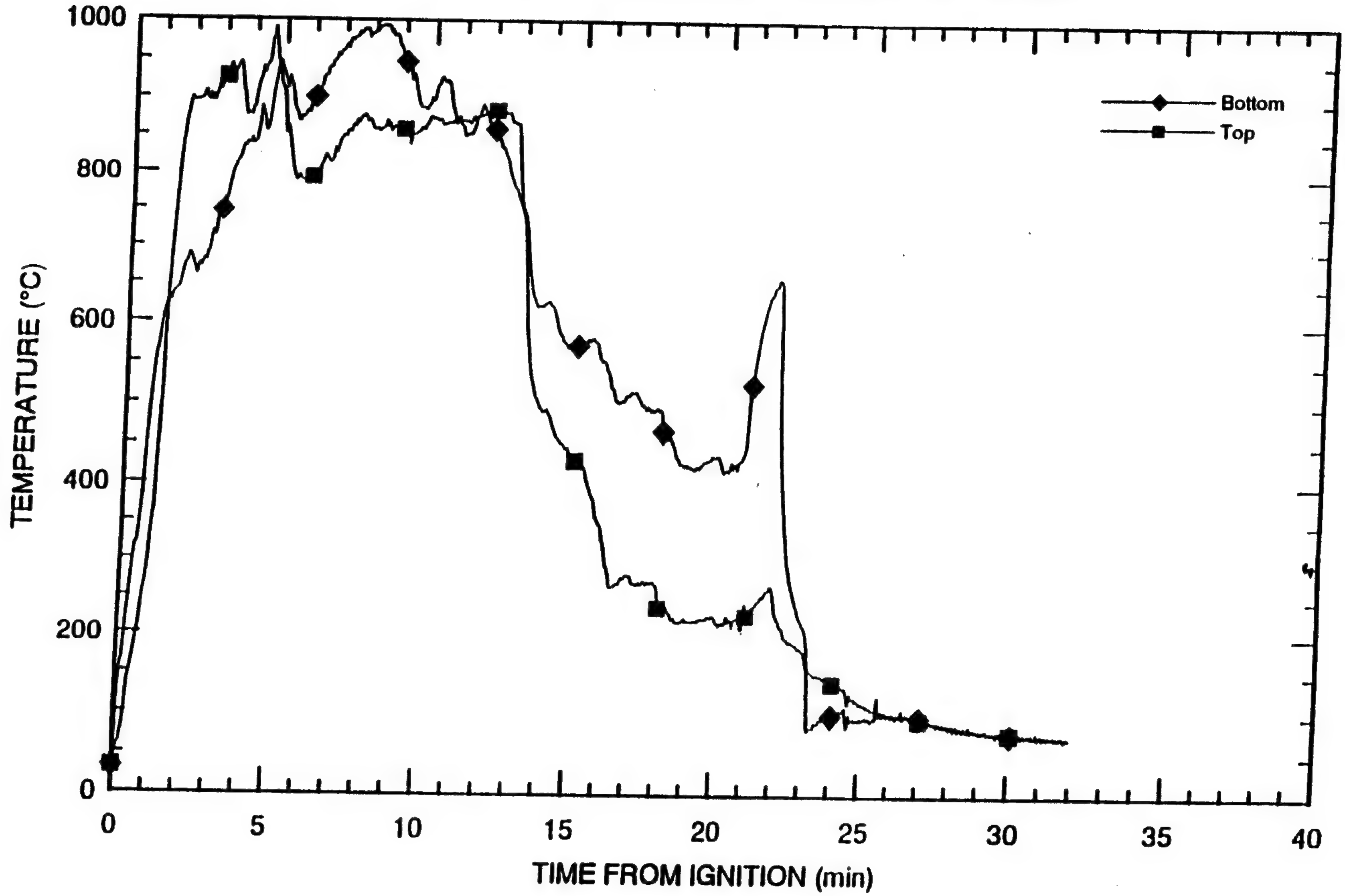


Fig. B91 - Wood crib #3 thermocouples for FOG_16

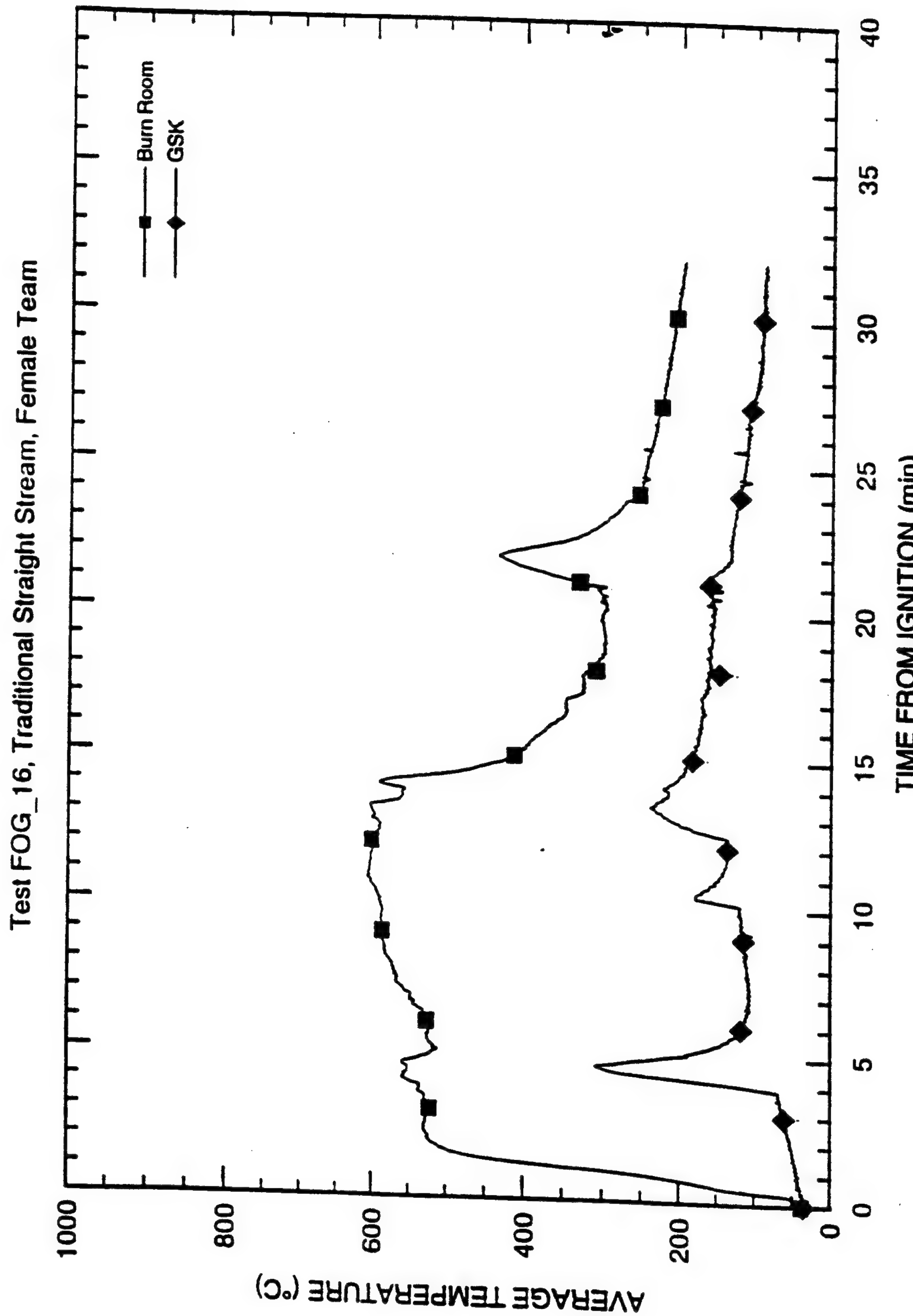


Fig. B92 - Average of overhead thermocouples for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

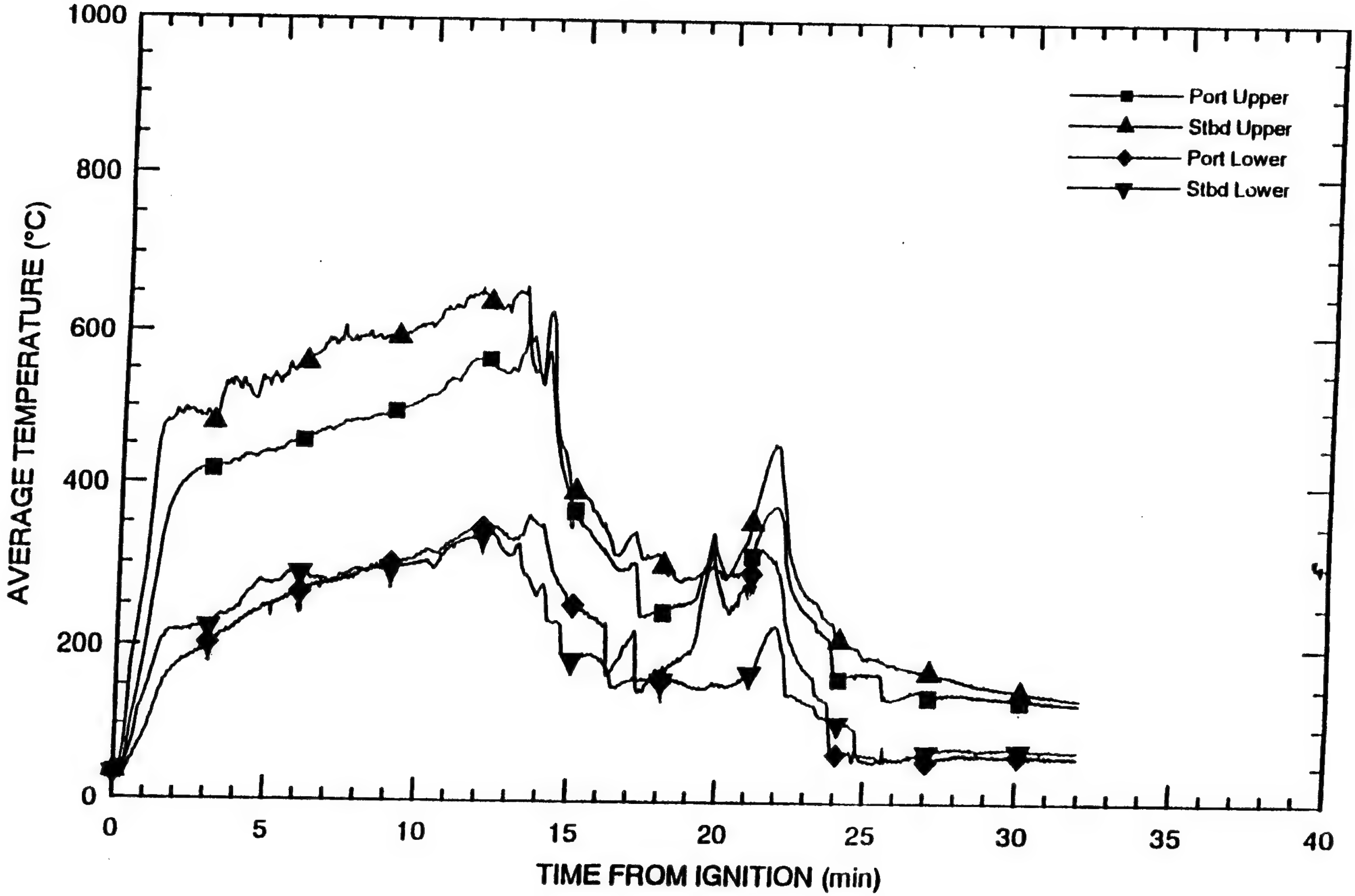


Fig. B93 - Burn room thermocouple string averages (upper vs. lower) for FOG_16

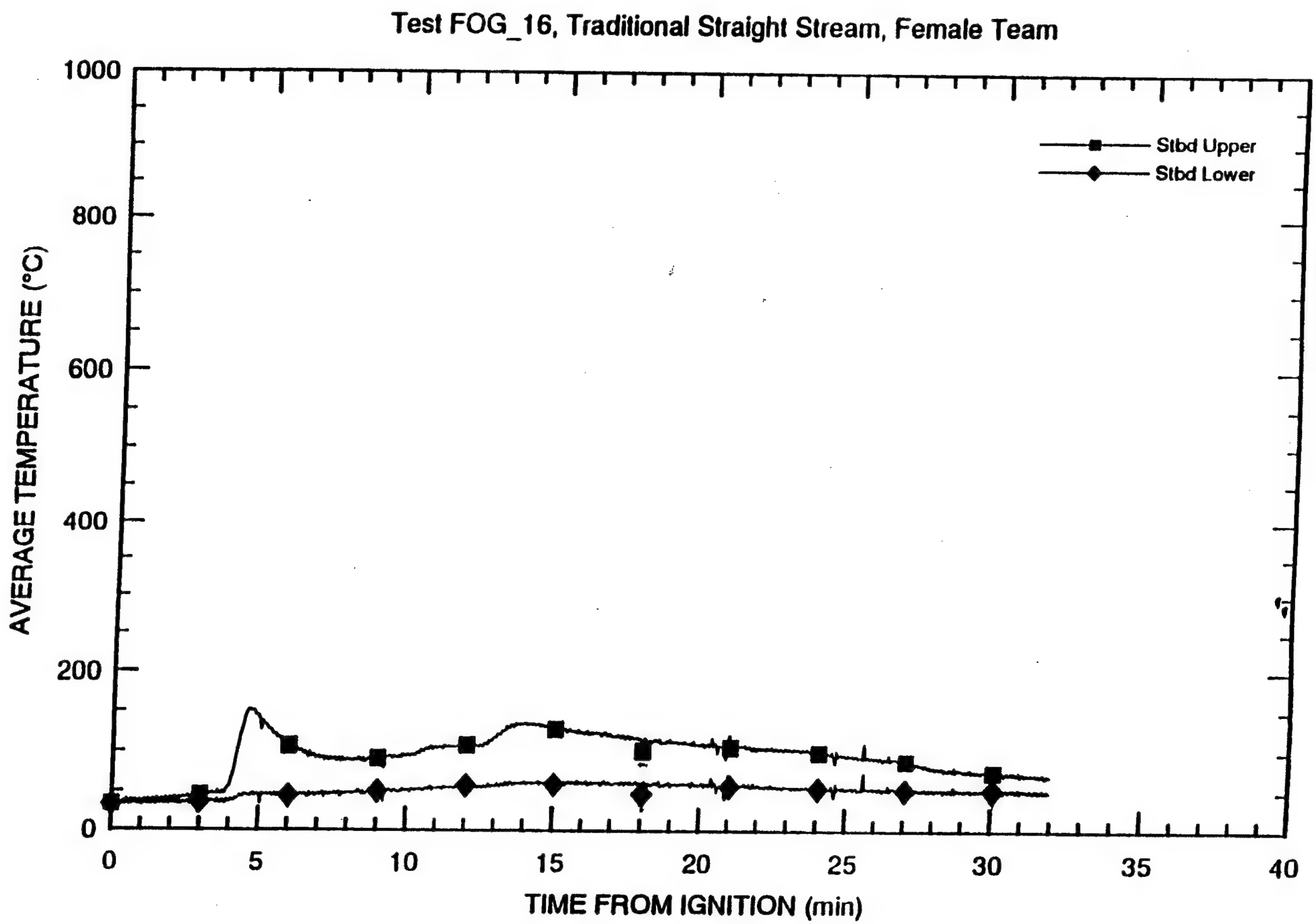


Fig. B94 - GSK thermocouple string averages (upper vs. lower) for FOG_16

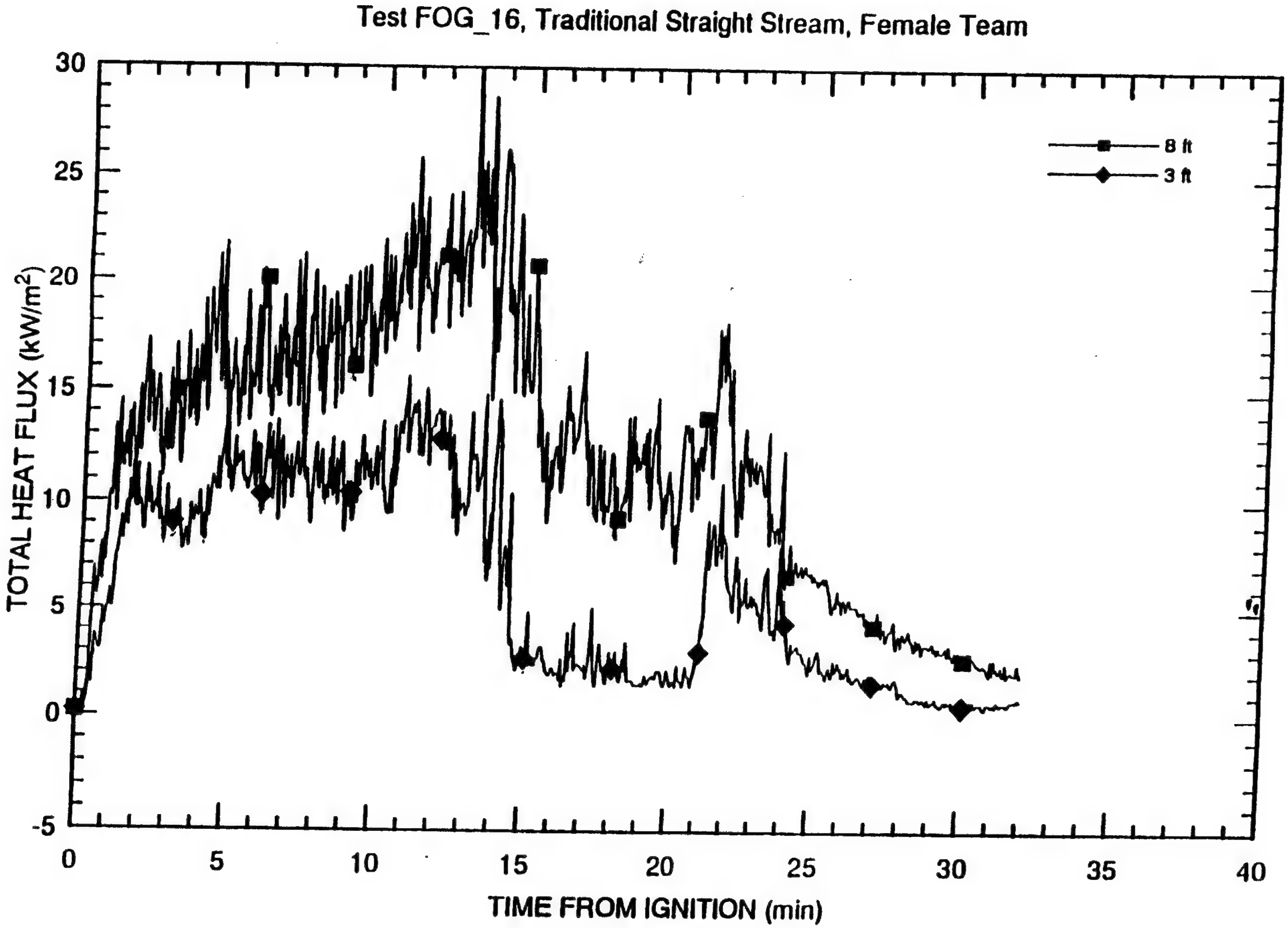


Fig. B95 - Burn room calorimeters for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

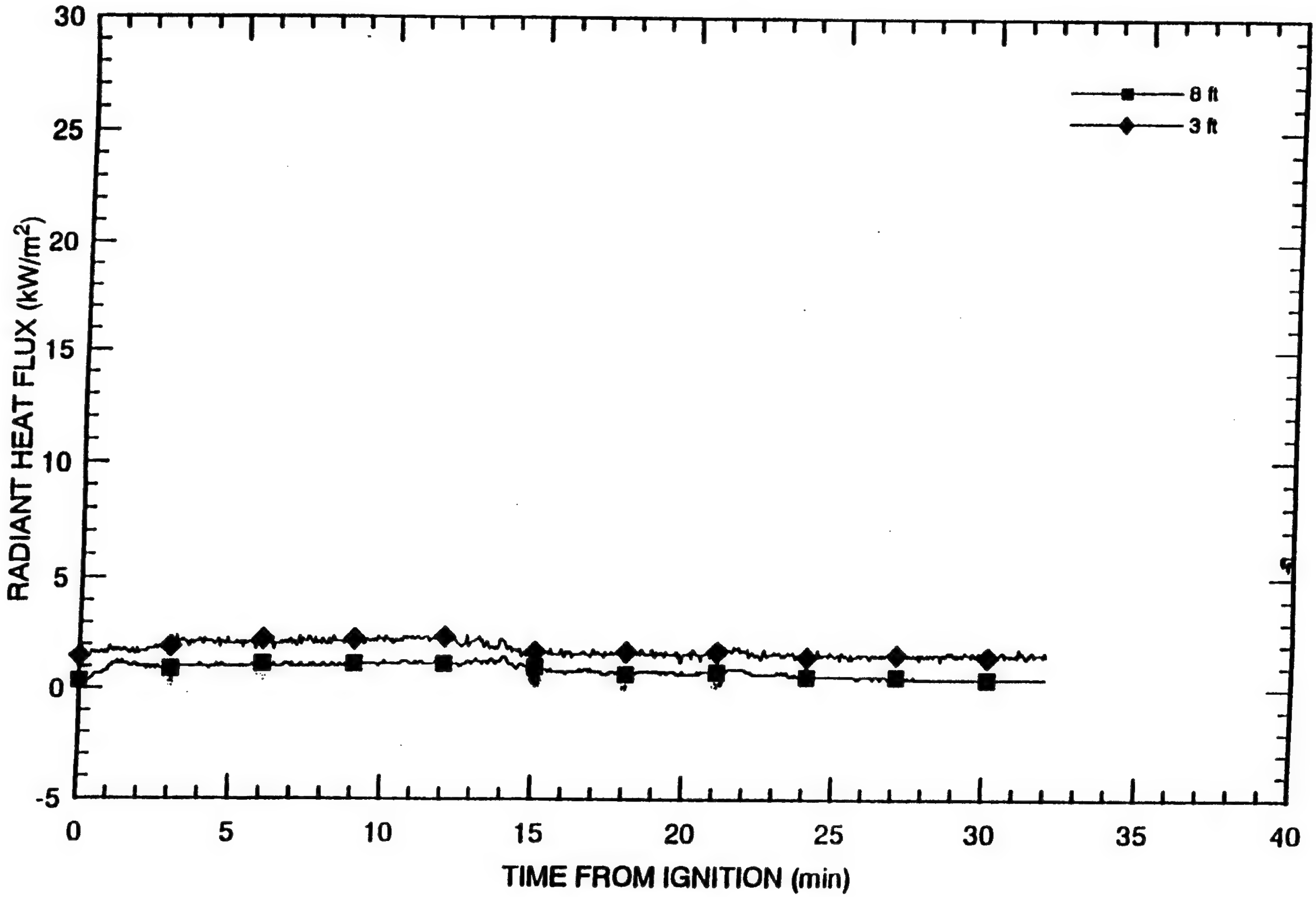


Fig. B96 - Burn room radiometers for FOG_16

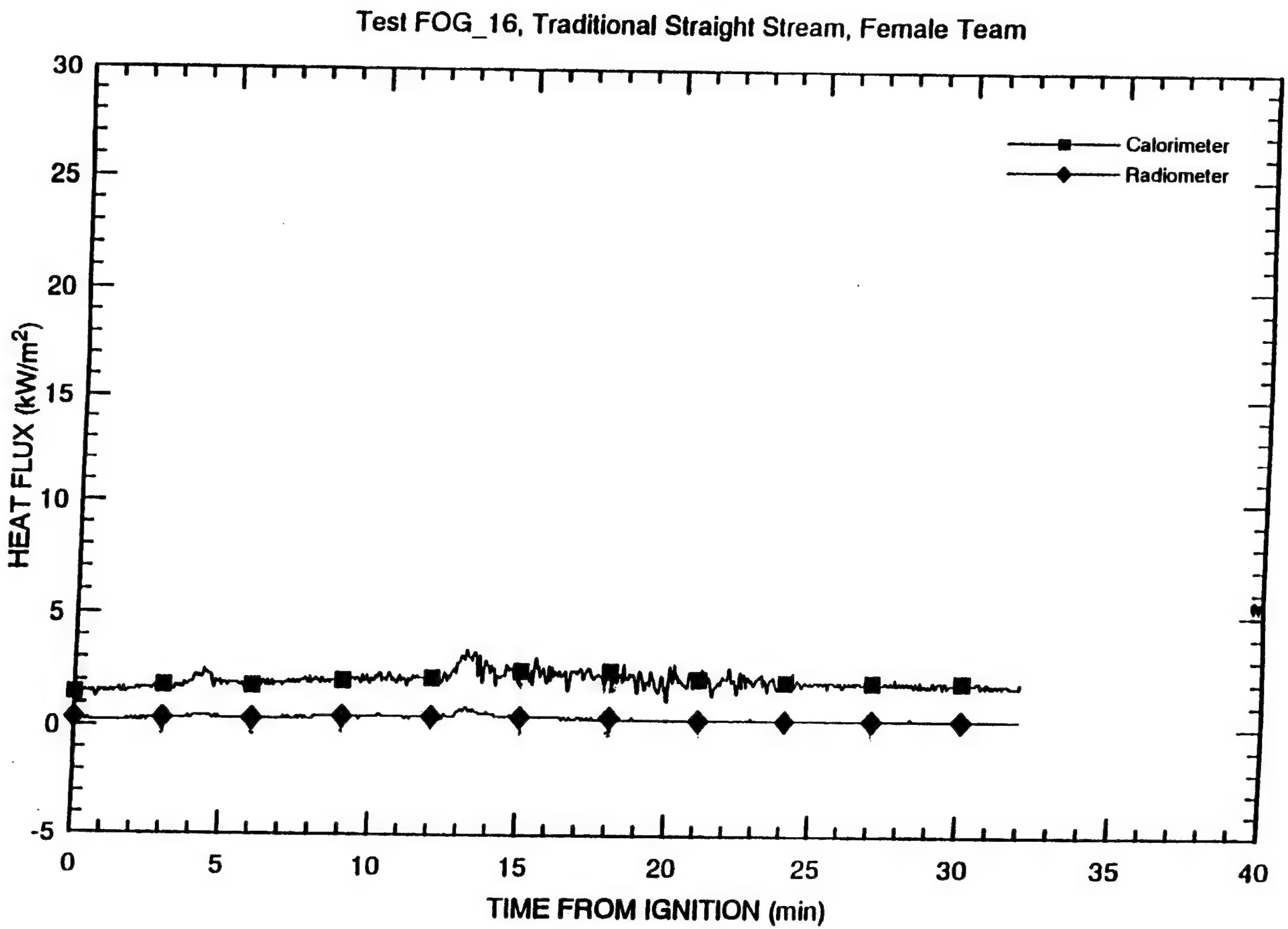


Fig. B97 - GSK radiometer and calorimeter for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

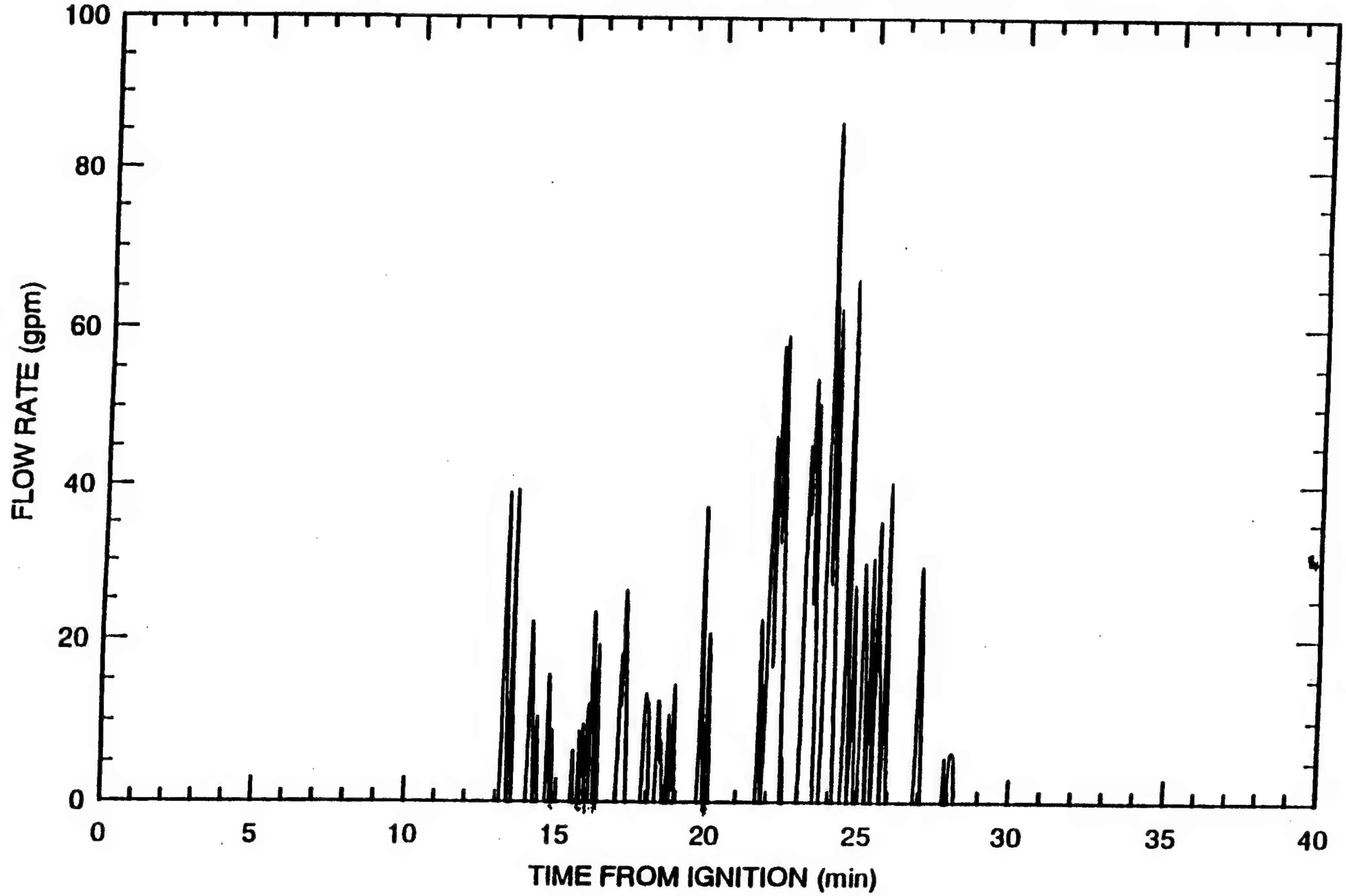


Fig. B98 - Water flow rate for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

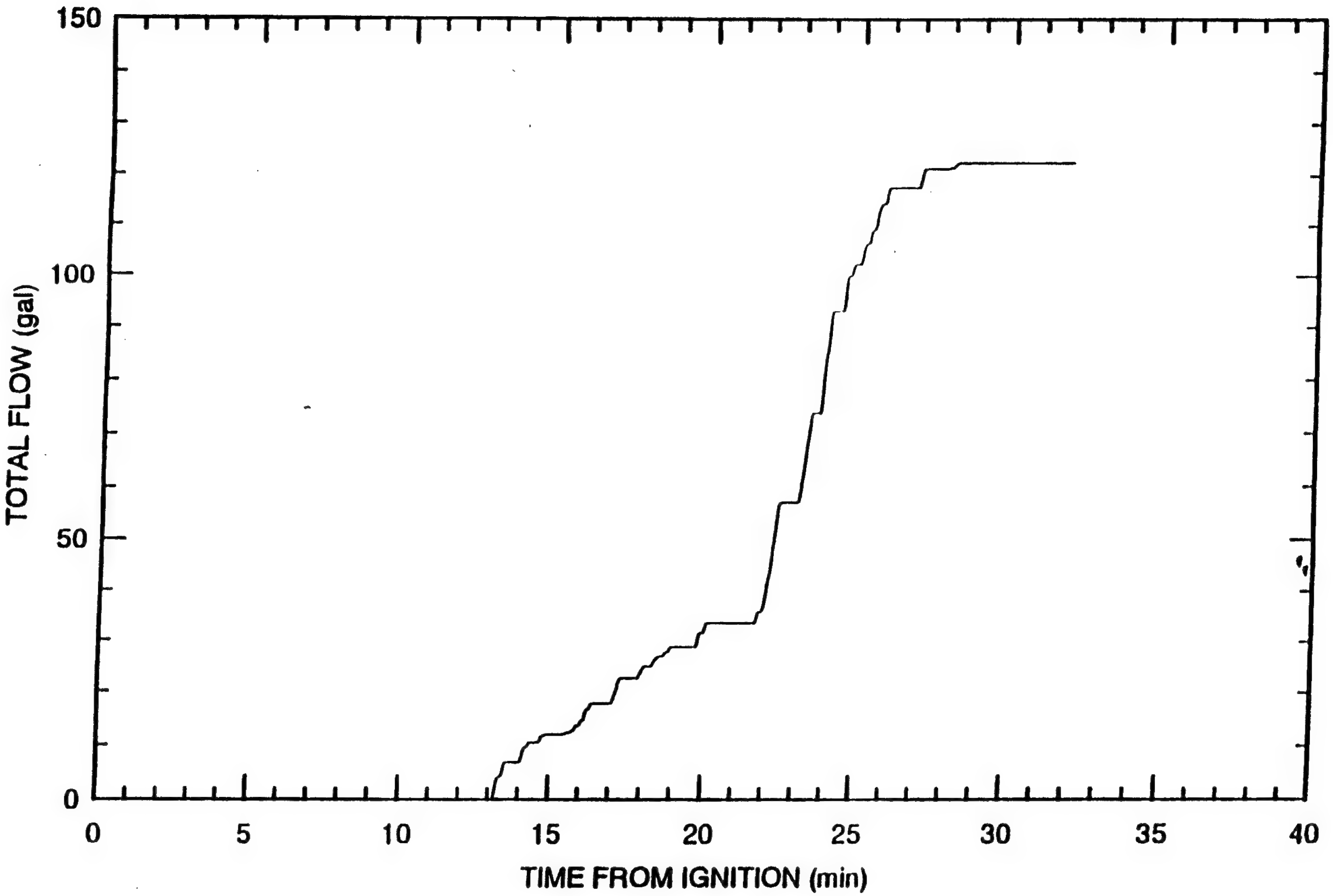


Fig. B99 - Cumulative water flow for FOG_16

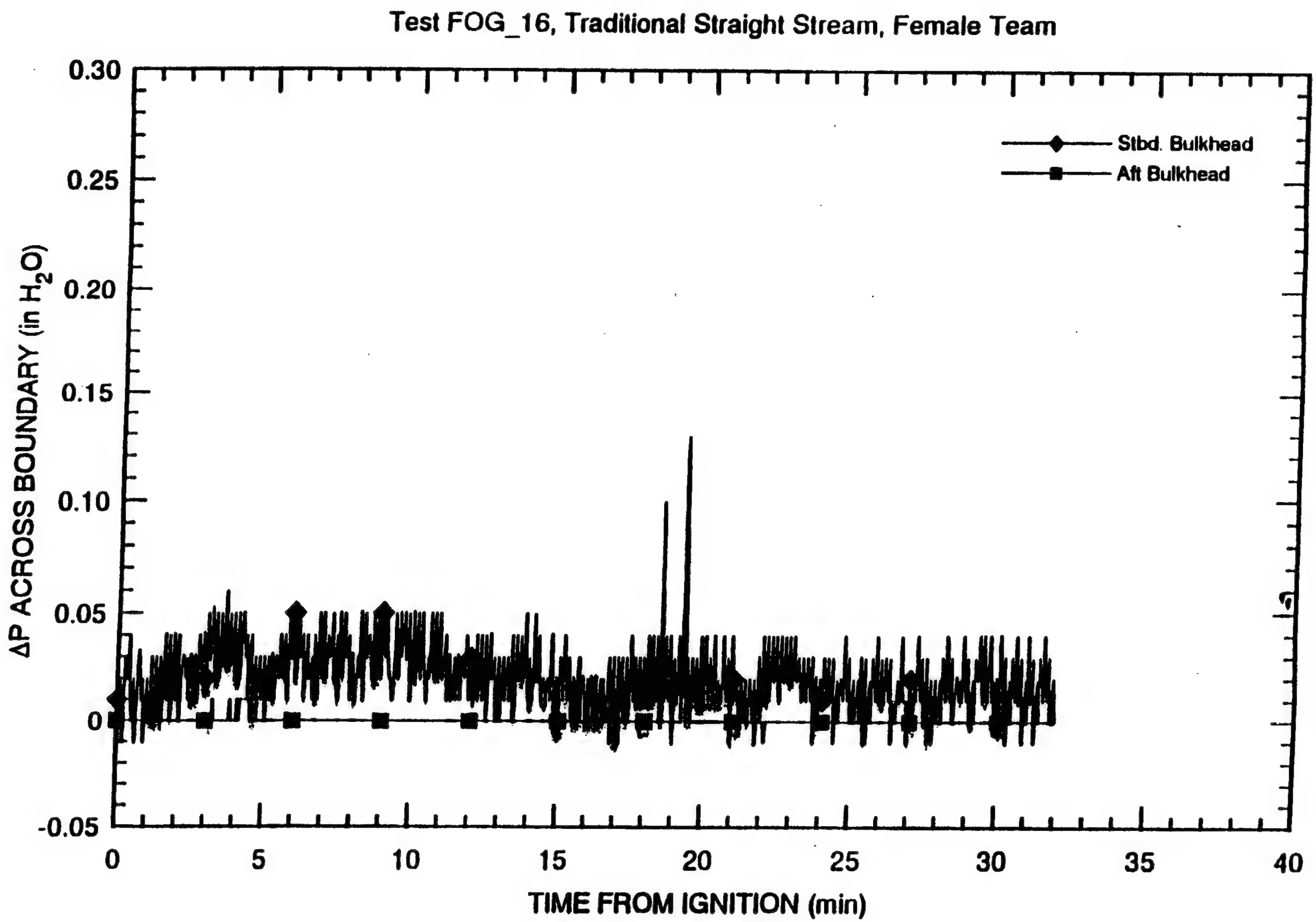


Fig. B100 - Pressure differential across burn room boundaries for FOG_16

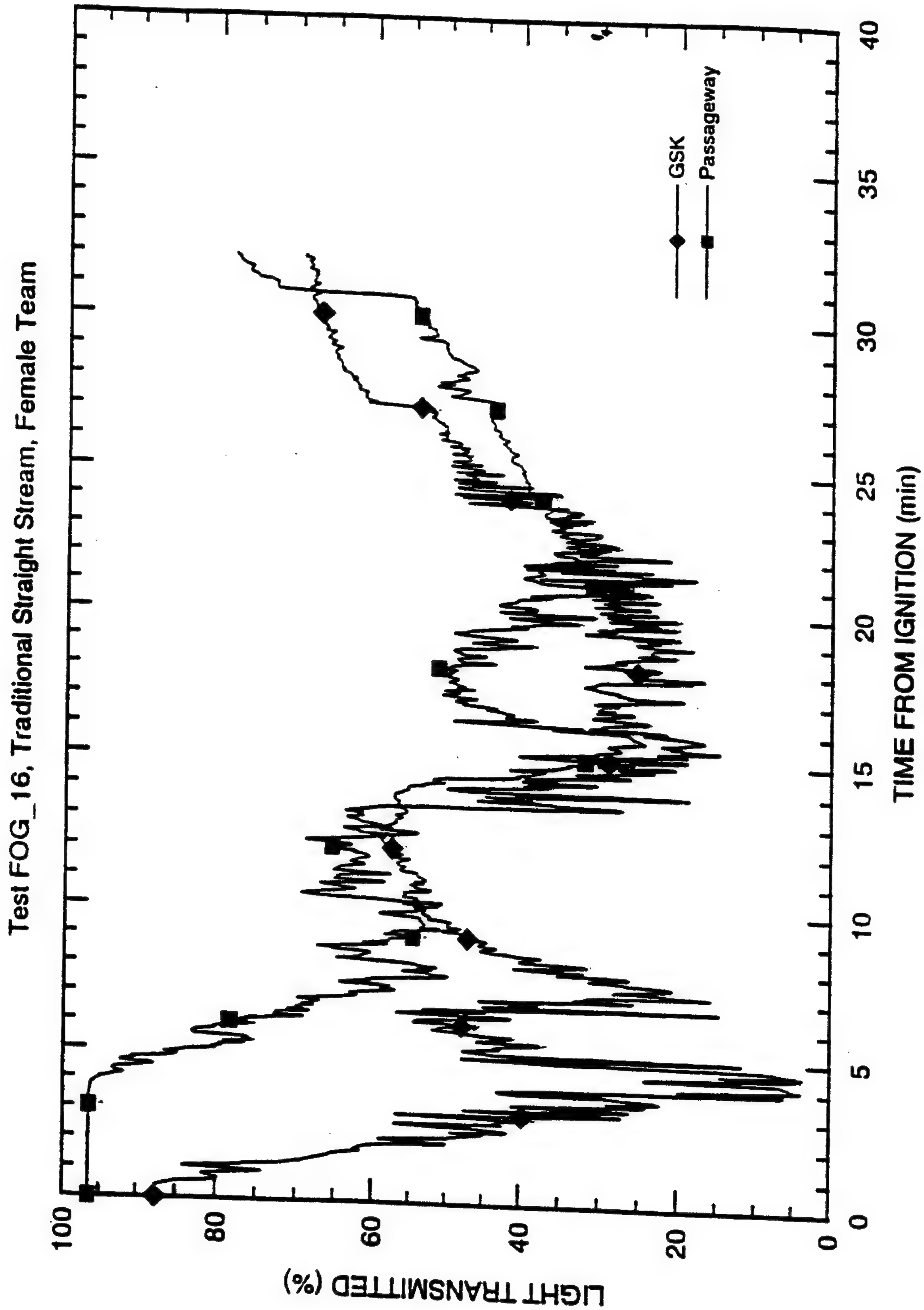


Fig. B101 - Smoke Obscuration for FOG_16

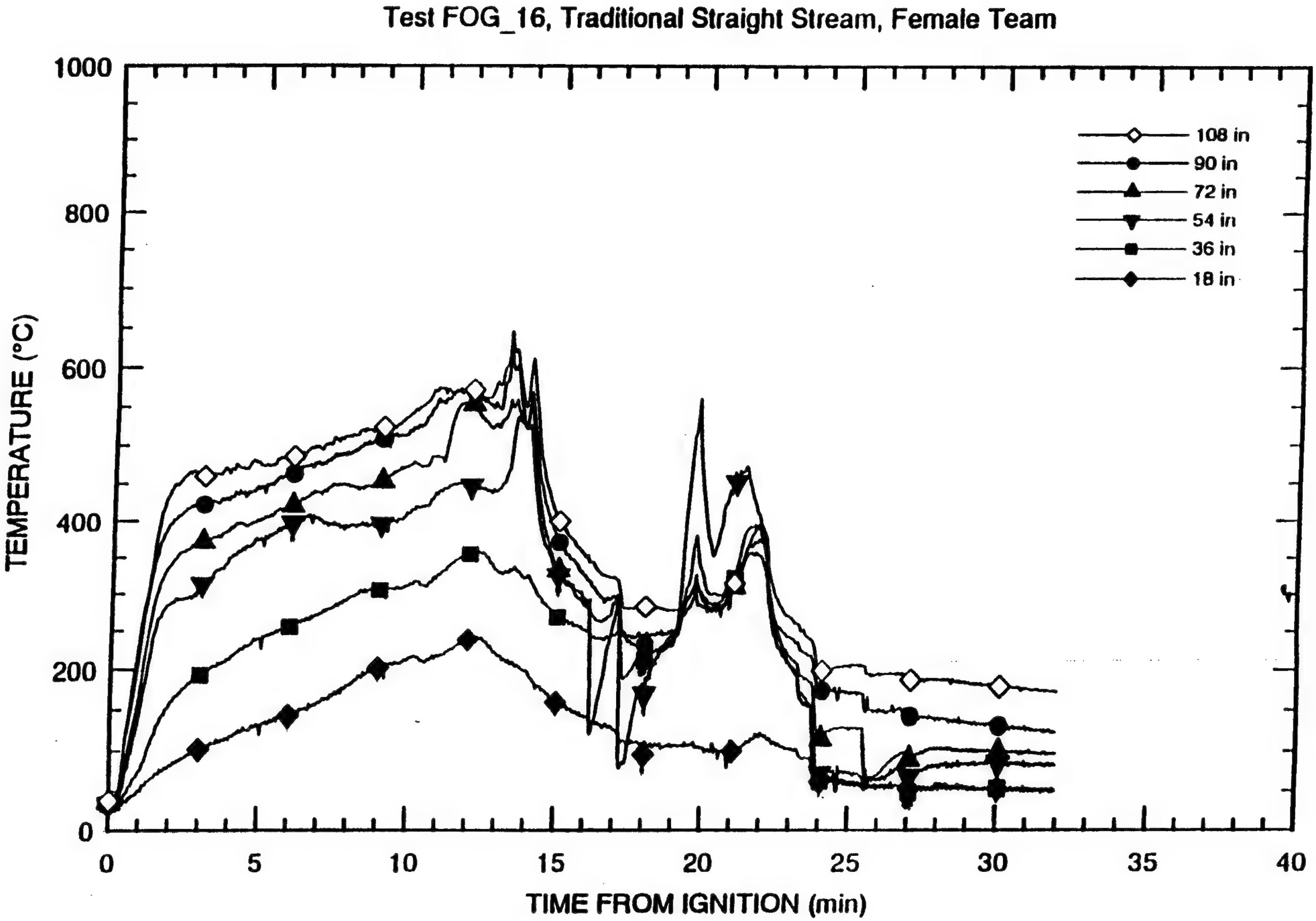


Fig. B102 - Port outer (2-18-2) thermocouple tree for FOG_16

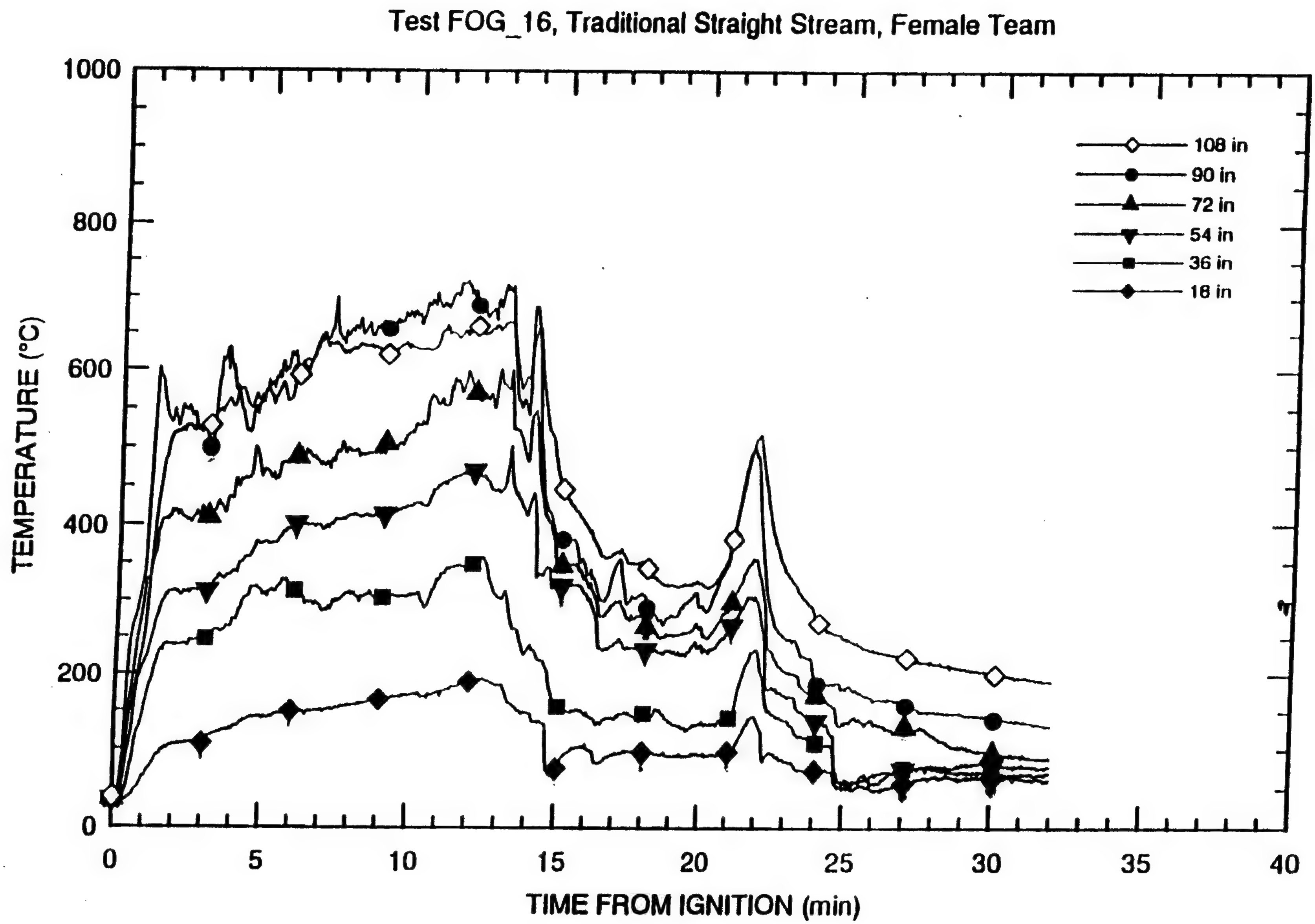


Fig. B103 - Port inner (2-19-0) thermocouple tree for FOG_16

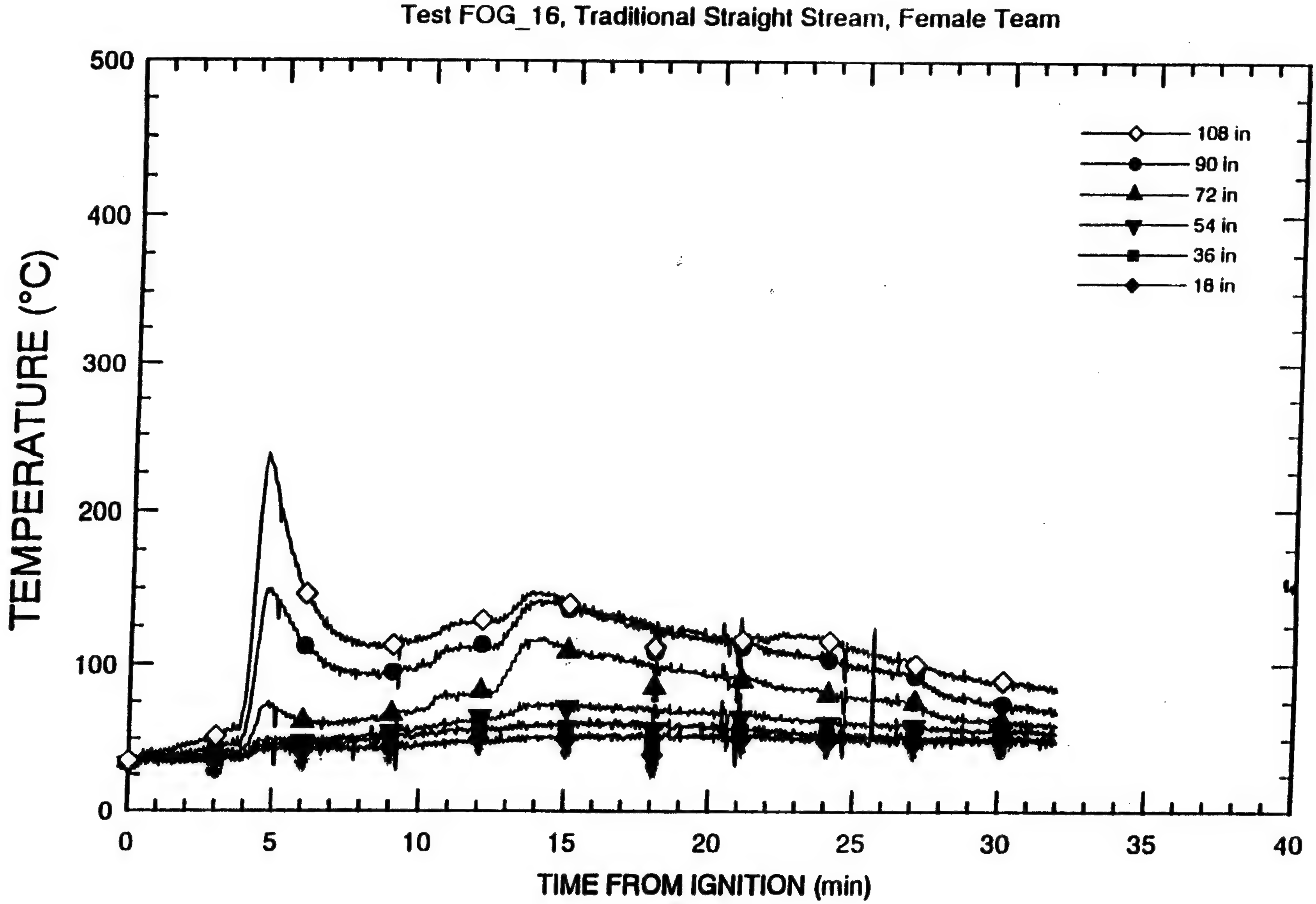


Fig. B104 - Starboard outer (2-21-3) thermocouple tree for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

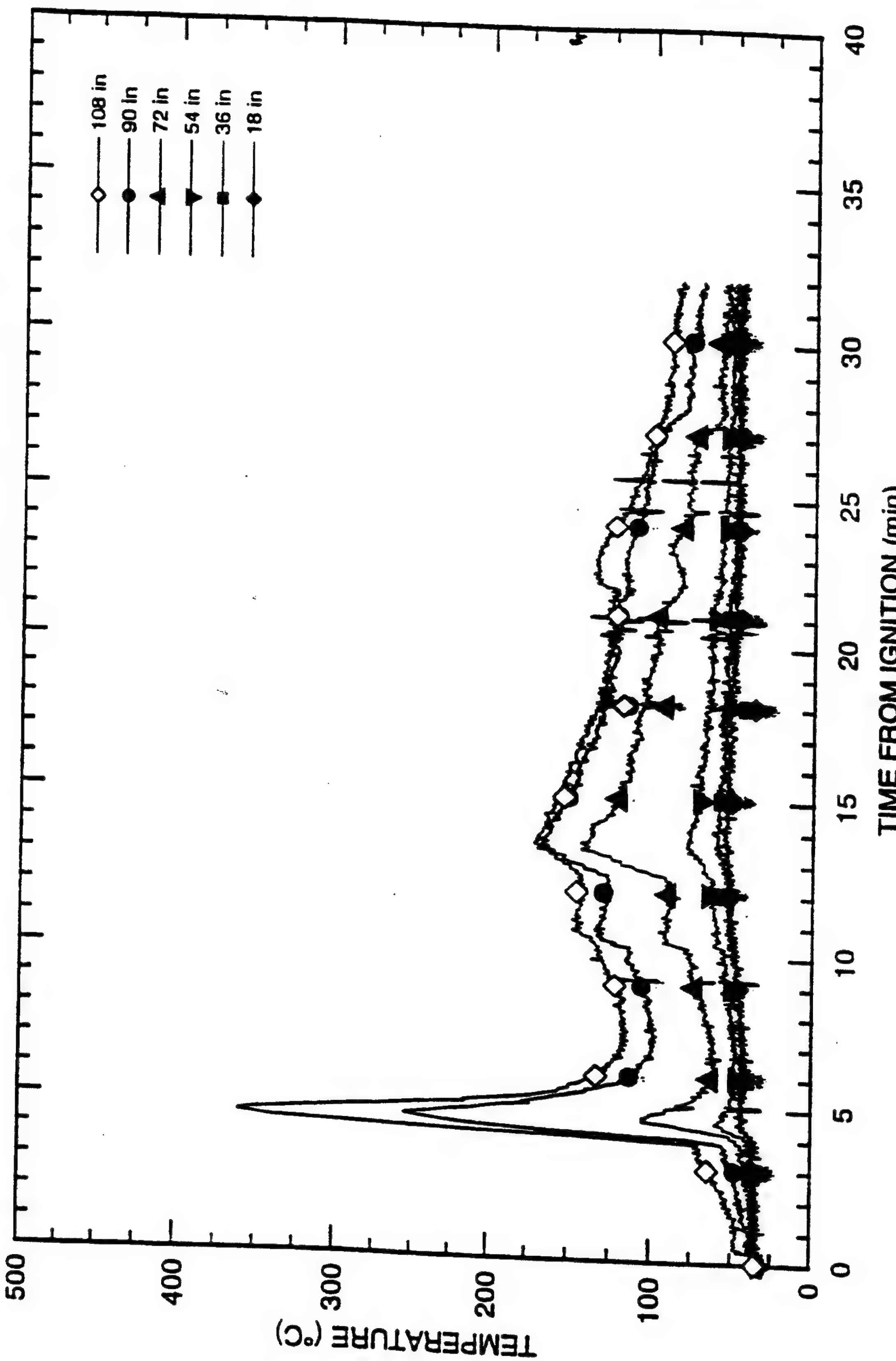


Fig. B105 - Starboard inner (2-21-1) thermocouple tree for FOG_16

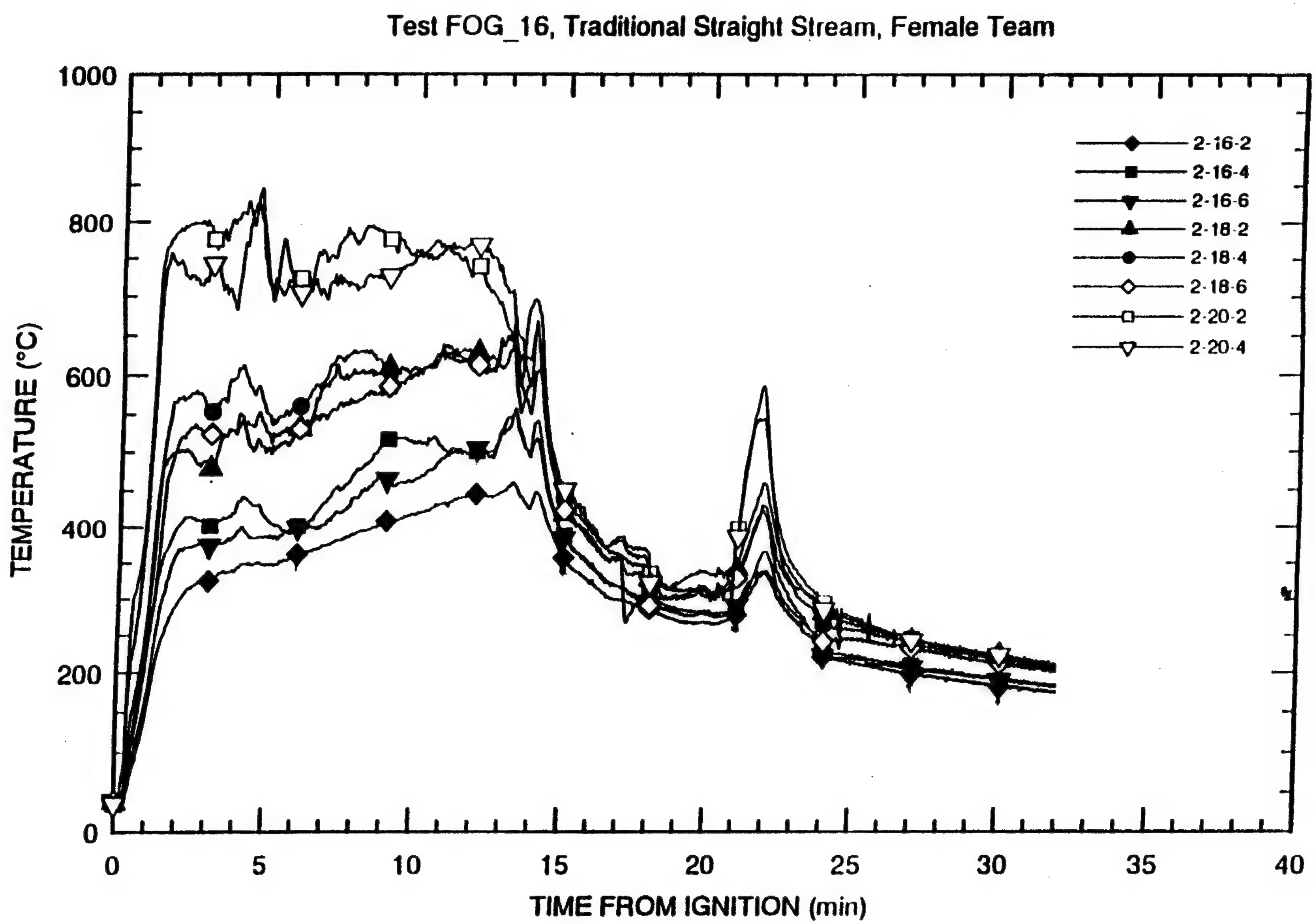


Fig. B106 - Burn room overhead temperatures for FOG_16

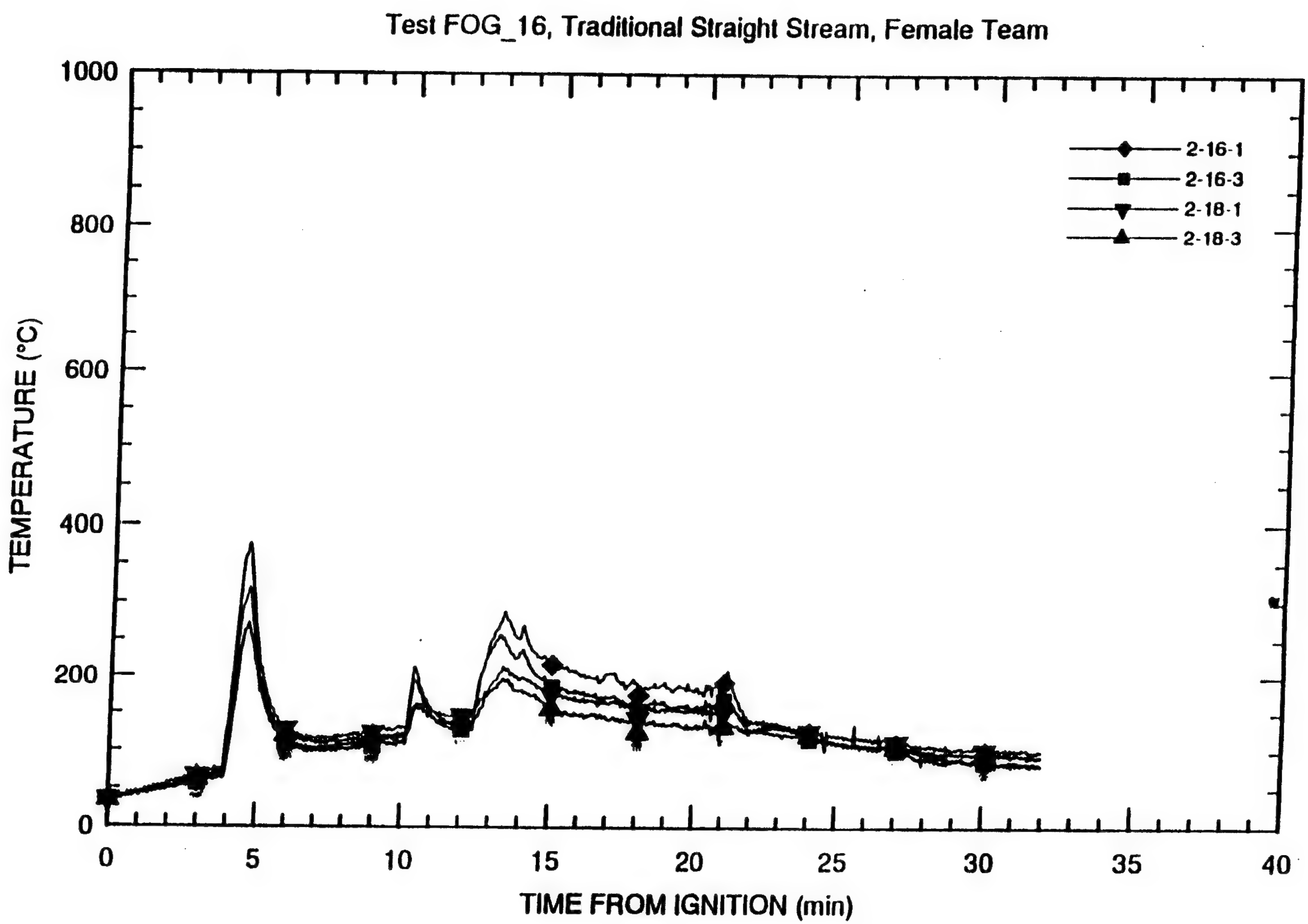


Fig. B107 - GSK overhead temperatures for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

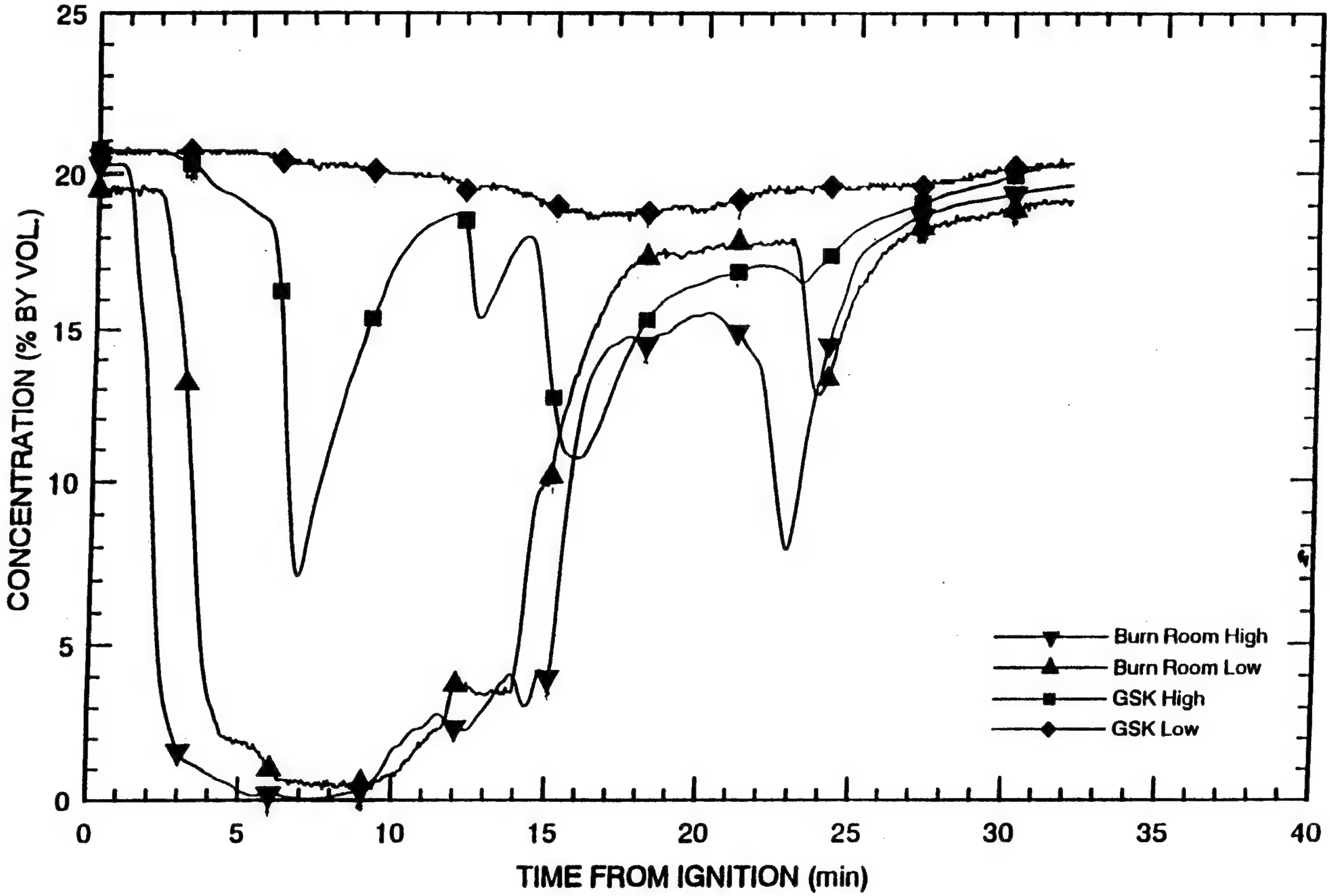


Fig. B108 - Oxygen (O_2) concentrations for FOG_16

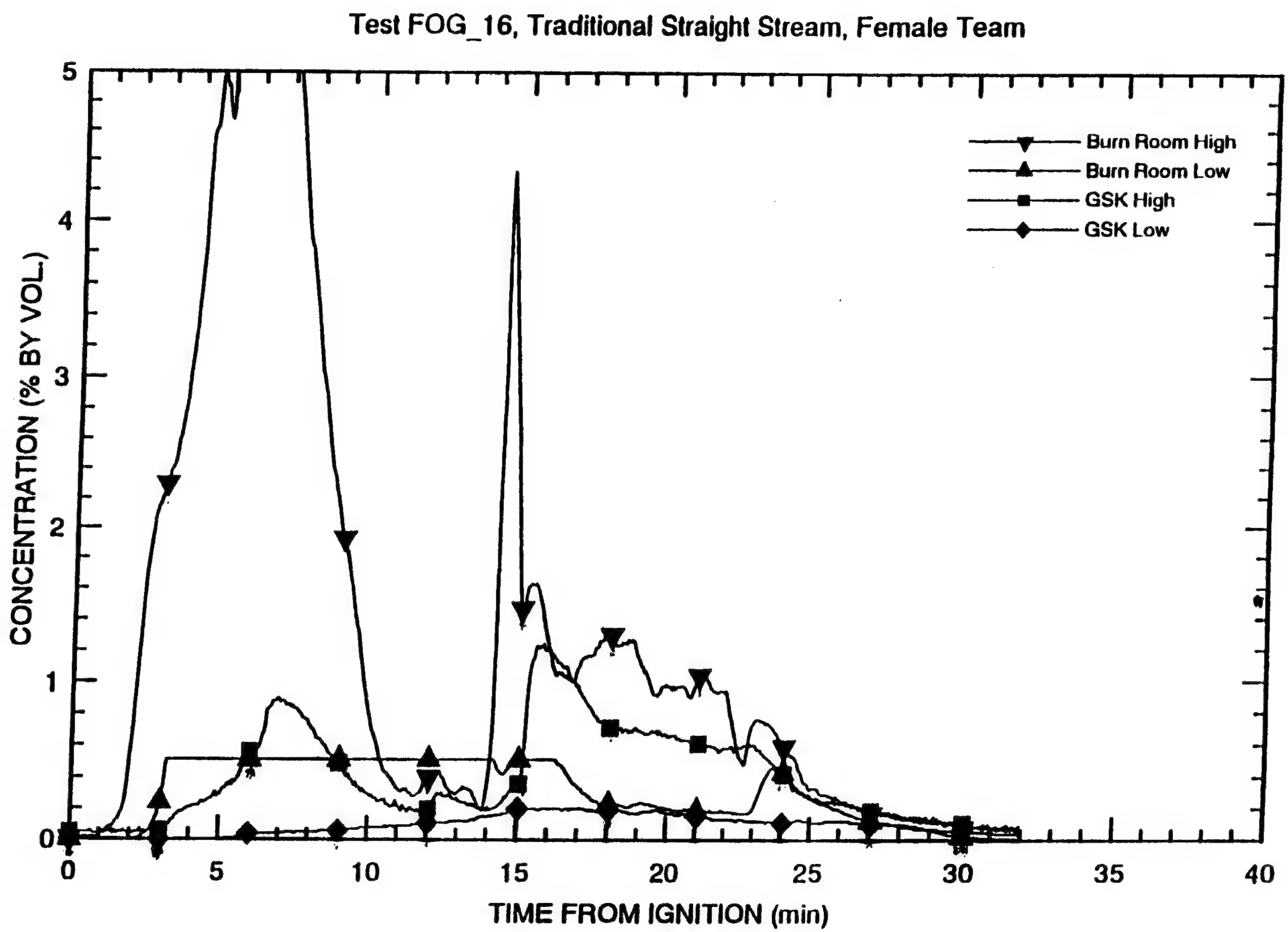


Fig. B109 - Carbon monoxide (CO) concentrations for FOG_16

Test FOG_16, Traditional Straight Stream, Female Team

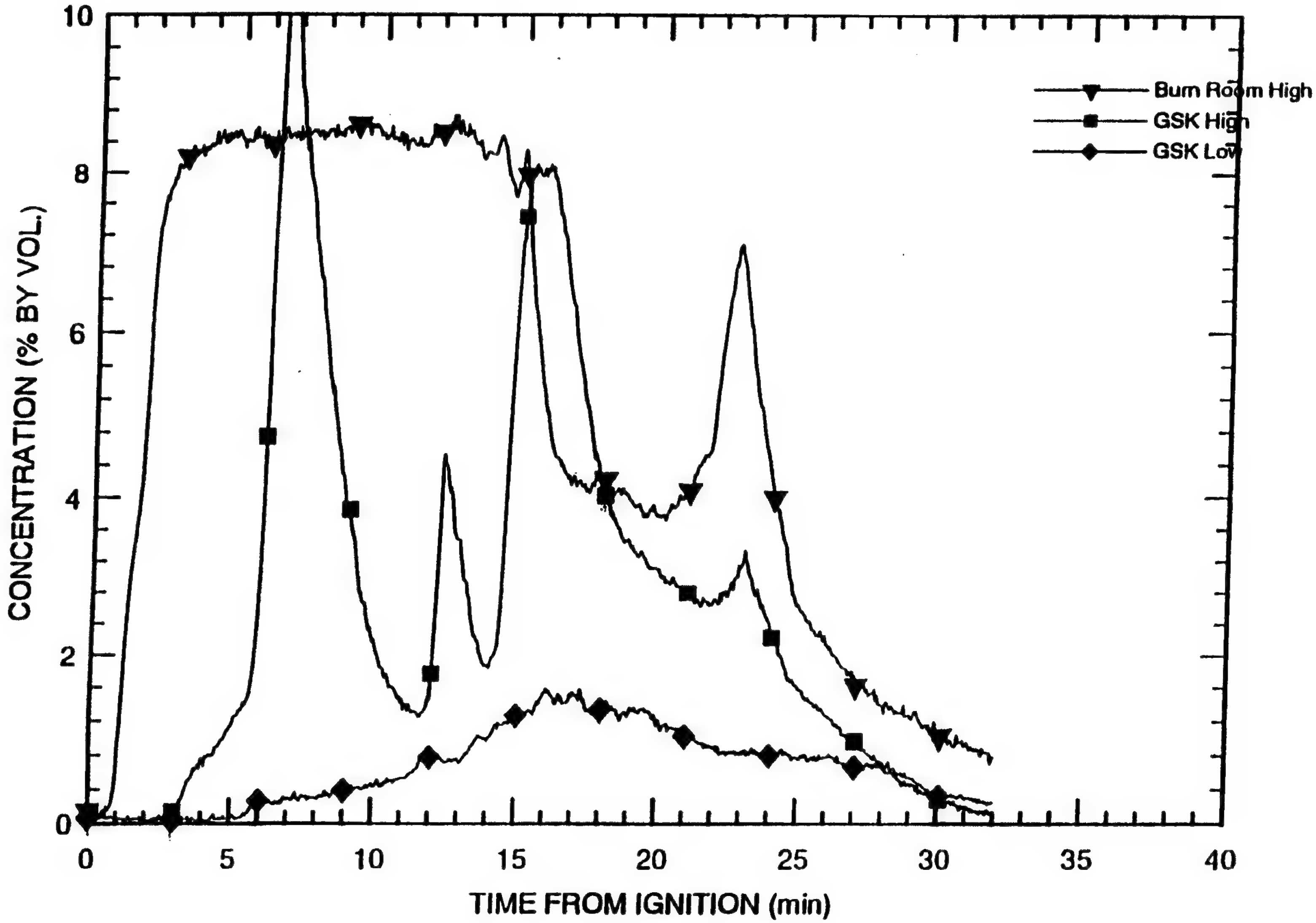


Fig. B110 - Carbon dioxide (CO_2) concentrations for FOG_16

Test FOG_17, Offensive Fog, PEB Team

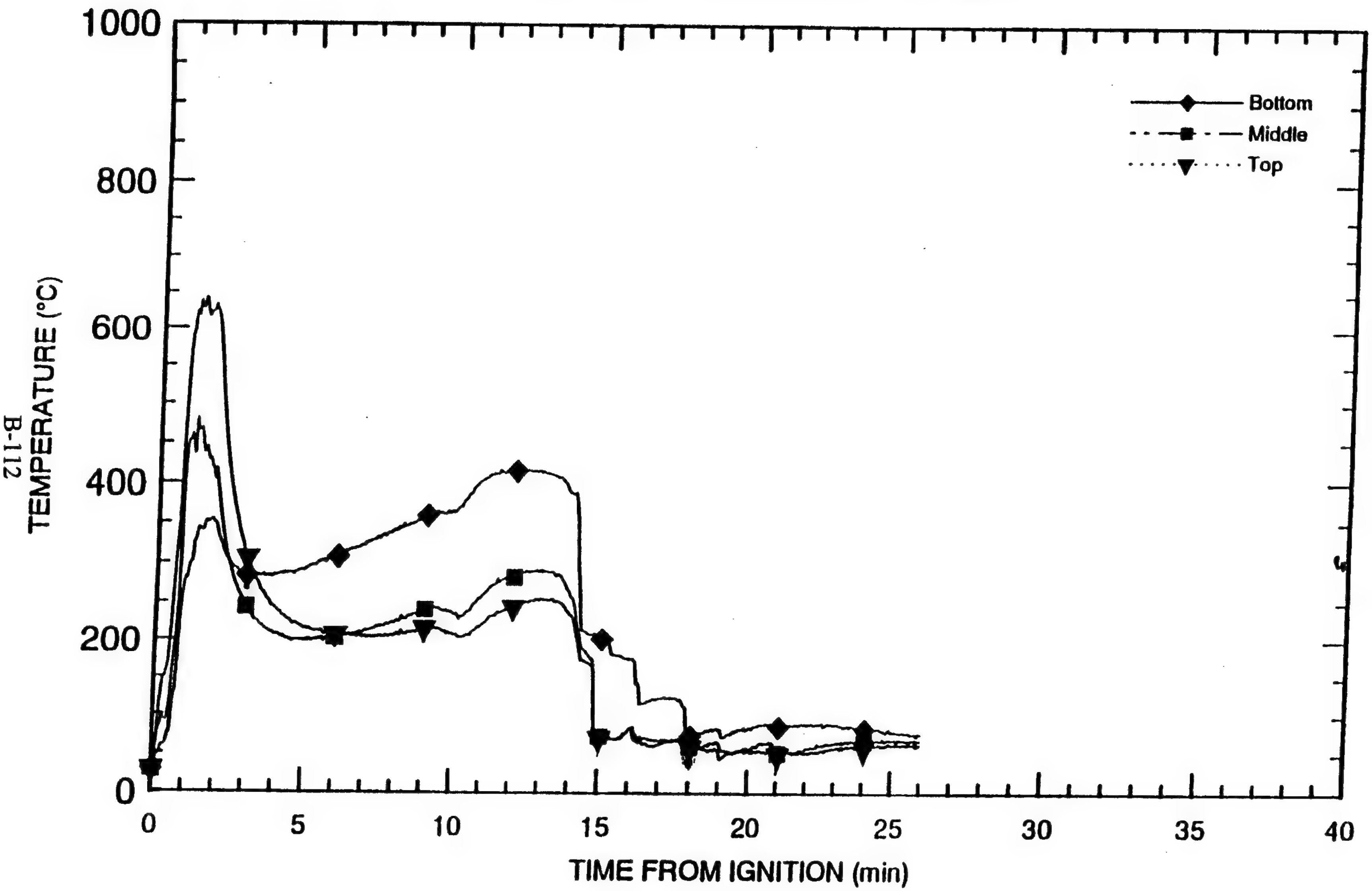


Fig. B111 - Wood crib #1 thermocouples for FOG_17

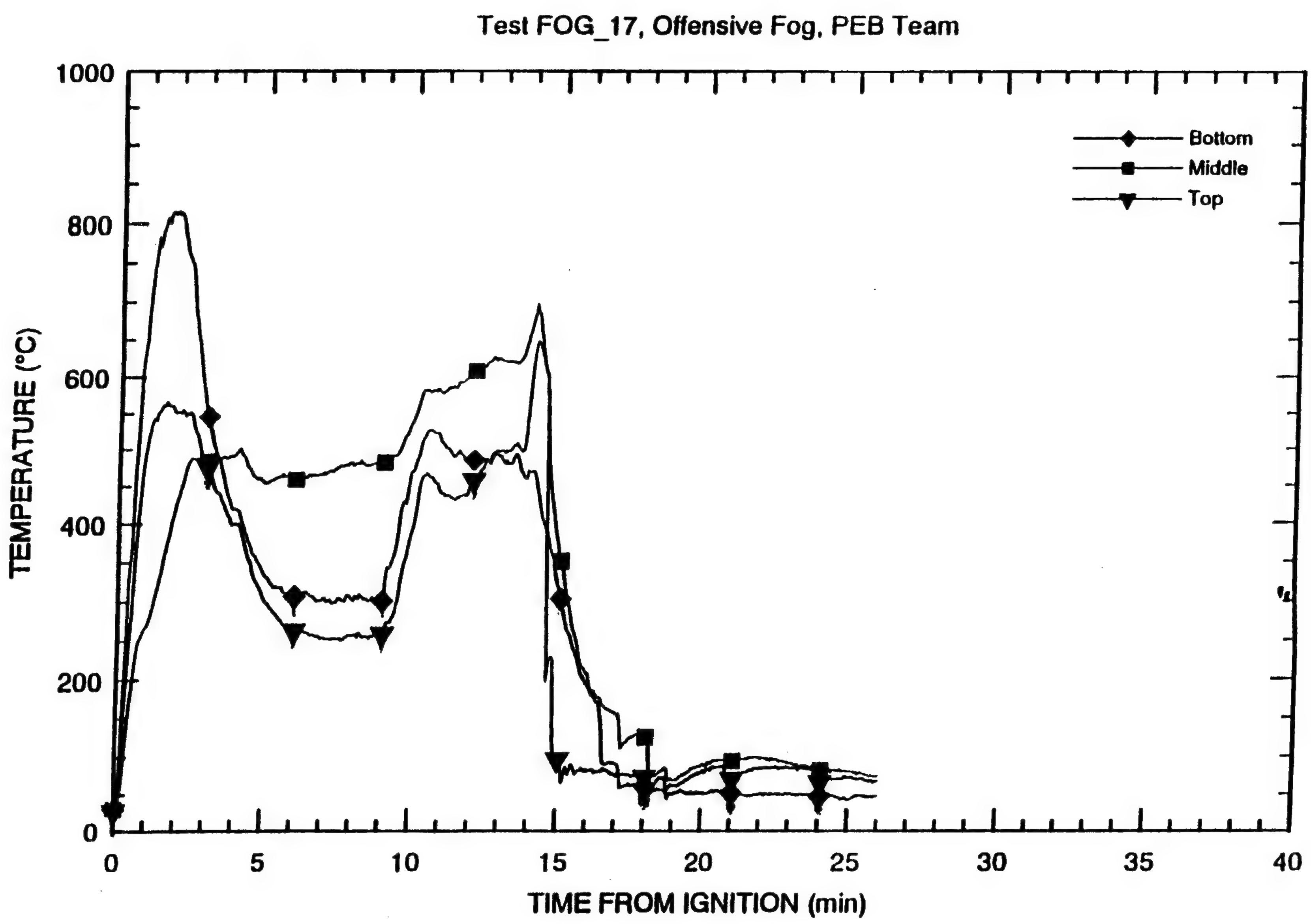


Fig. B112 - Wood crib #2 thermocouples for FOG_17

Test FOG_17, Offensive Fog, PEB Team

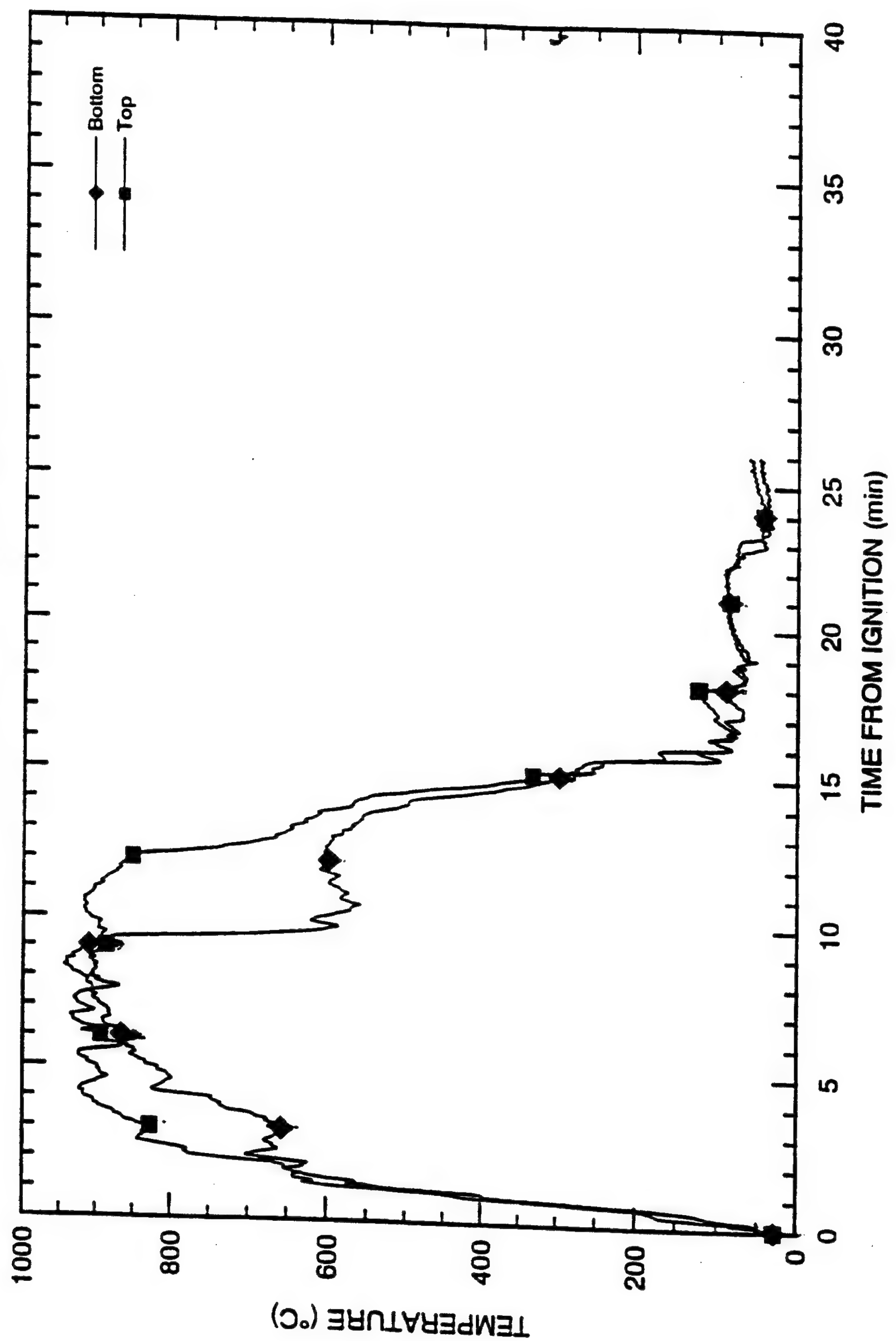


Fig. B113 - Wood crib #3 thermocouples for FOG_17

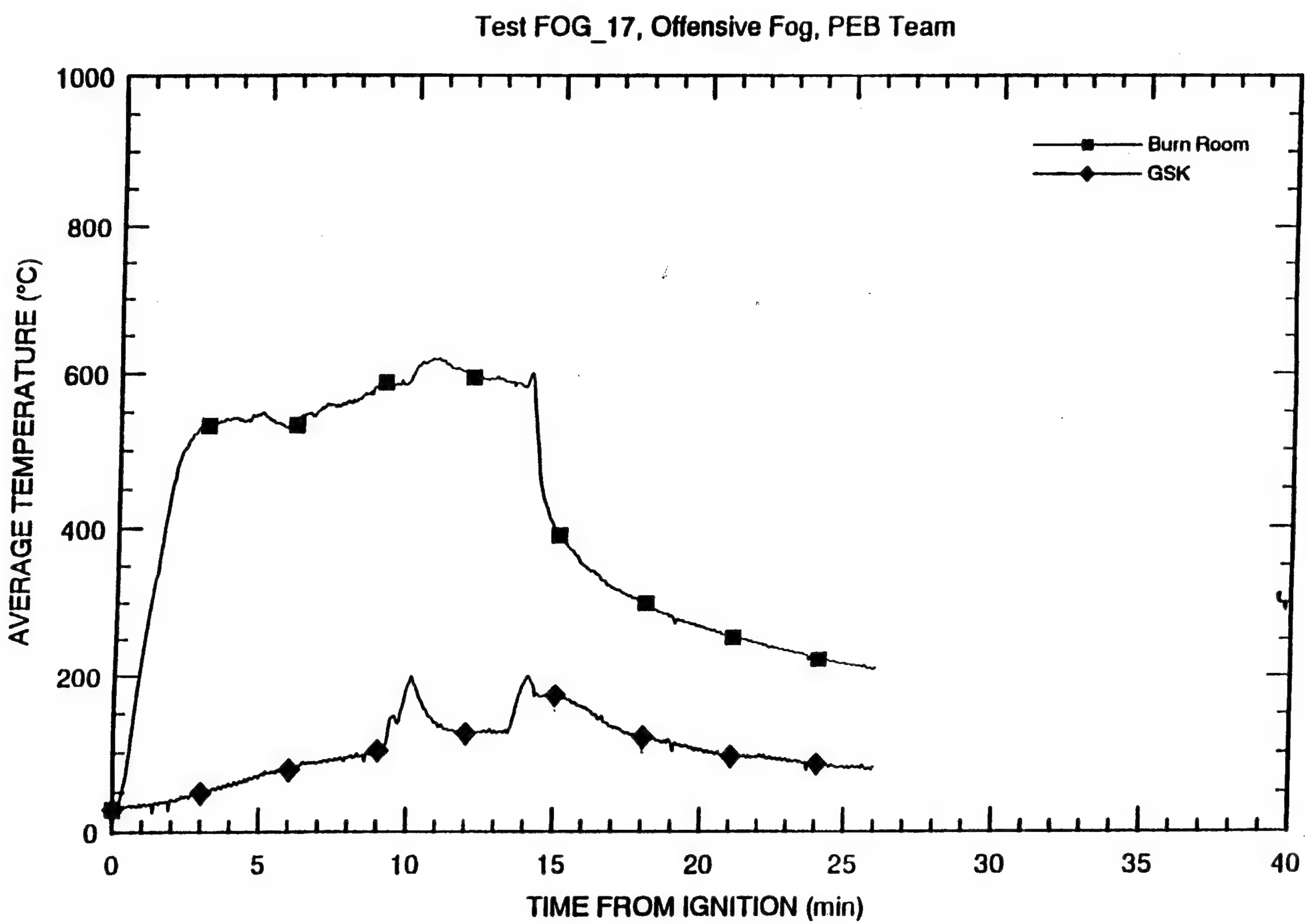


Fig. B114 - Average of overhead thermocouples for FOG_17

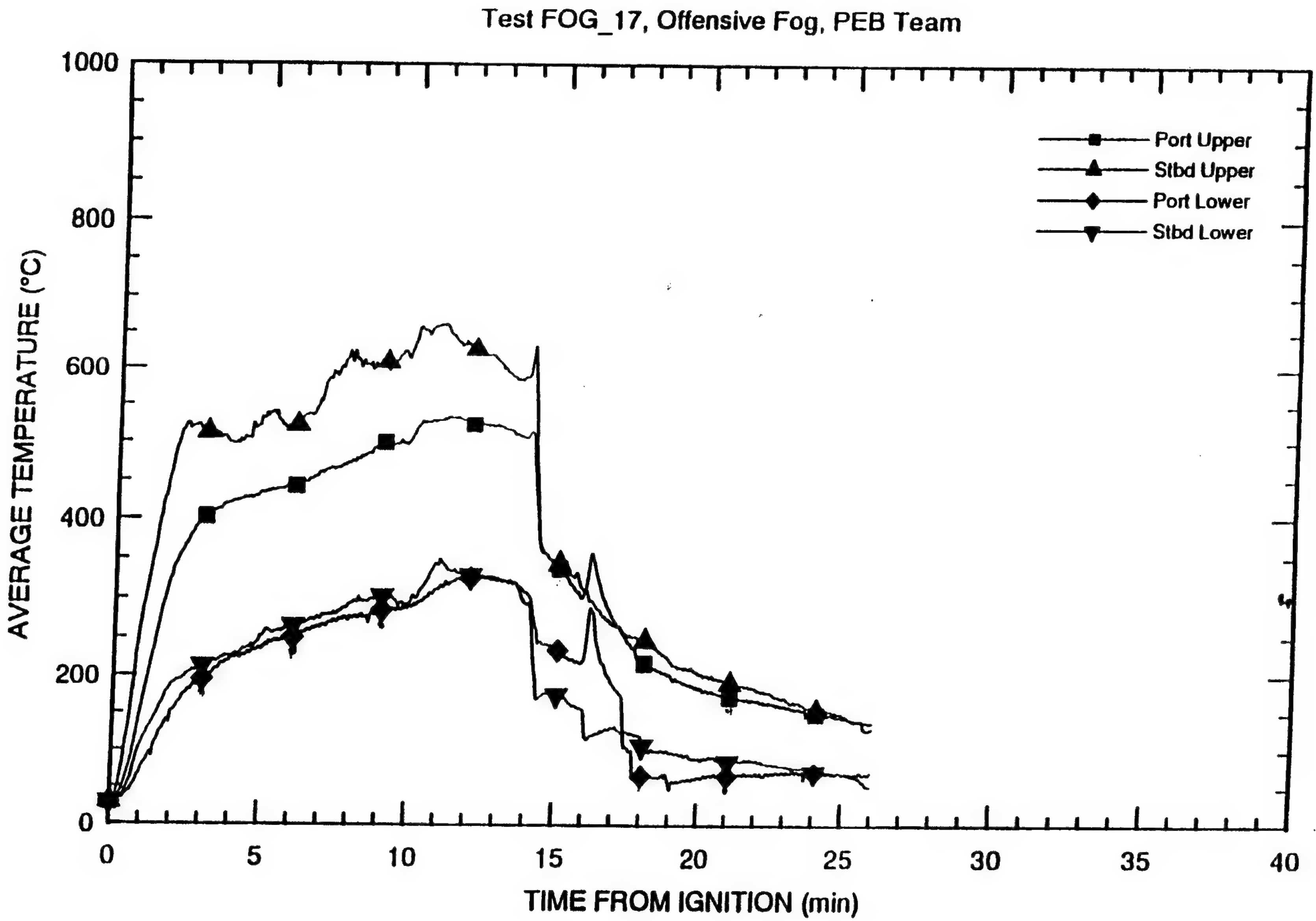


Fig. B115 - Burn room thermocouple string averages (upper vs. lower) for FOG_17

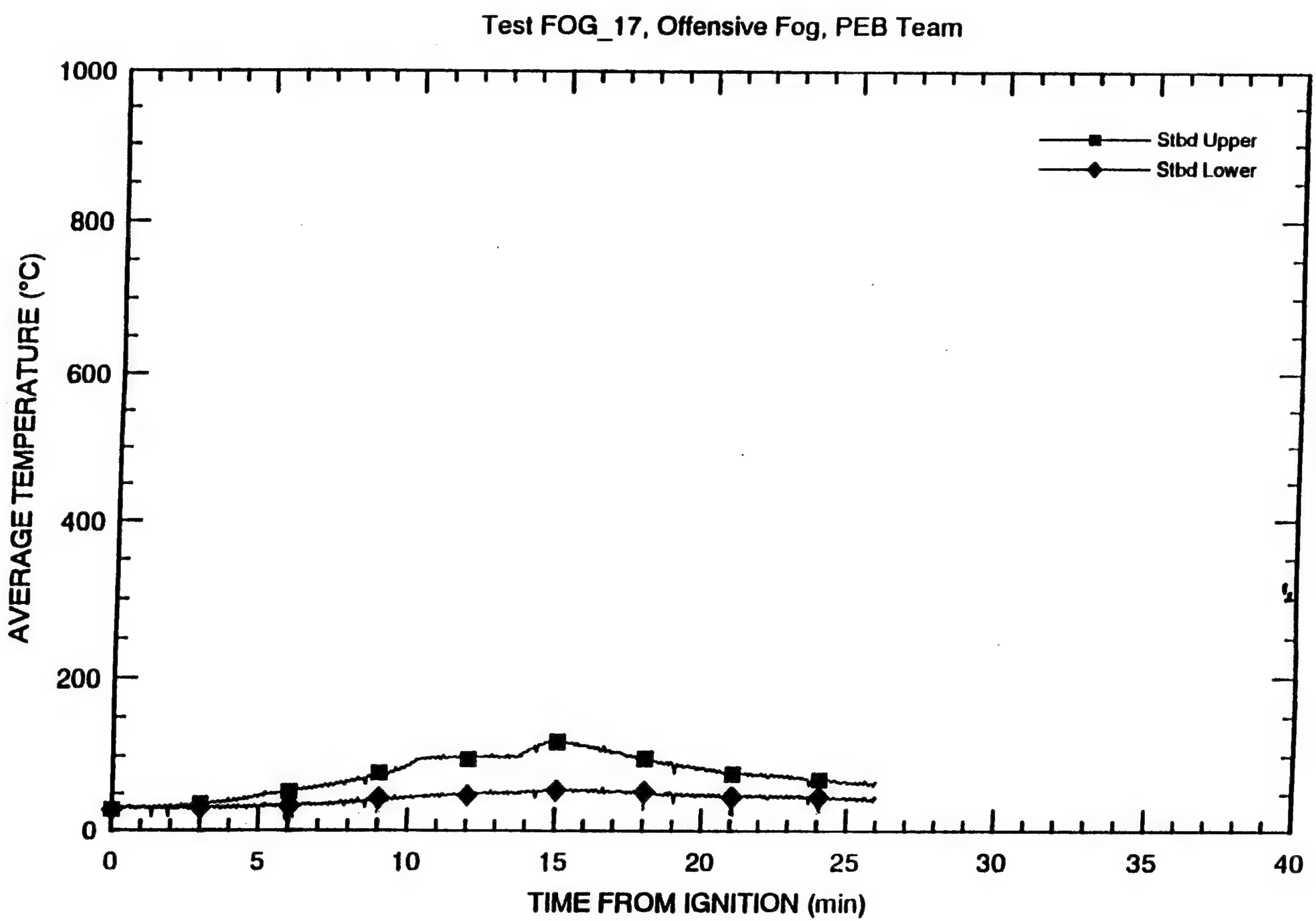


Fig. B116 - GSK thermocouple string averages (upper vs. lower) for FOG_17

Test FOG_17, Offensive Fog, PEB Team

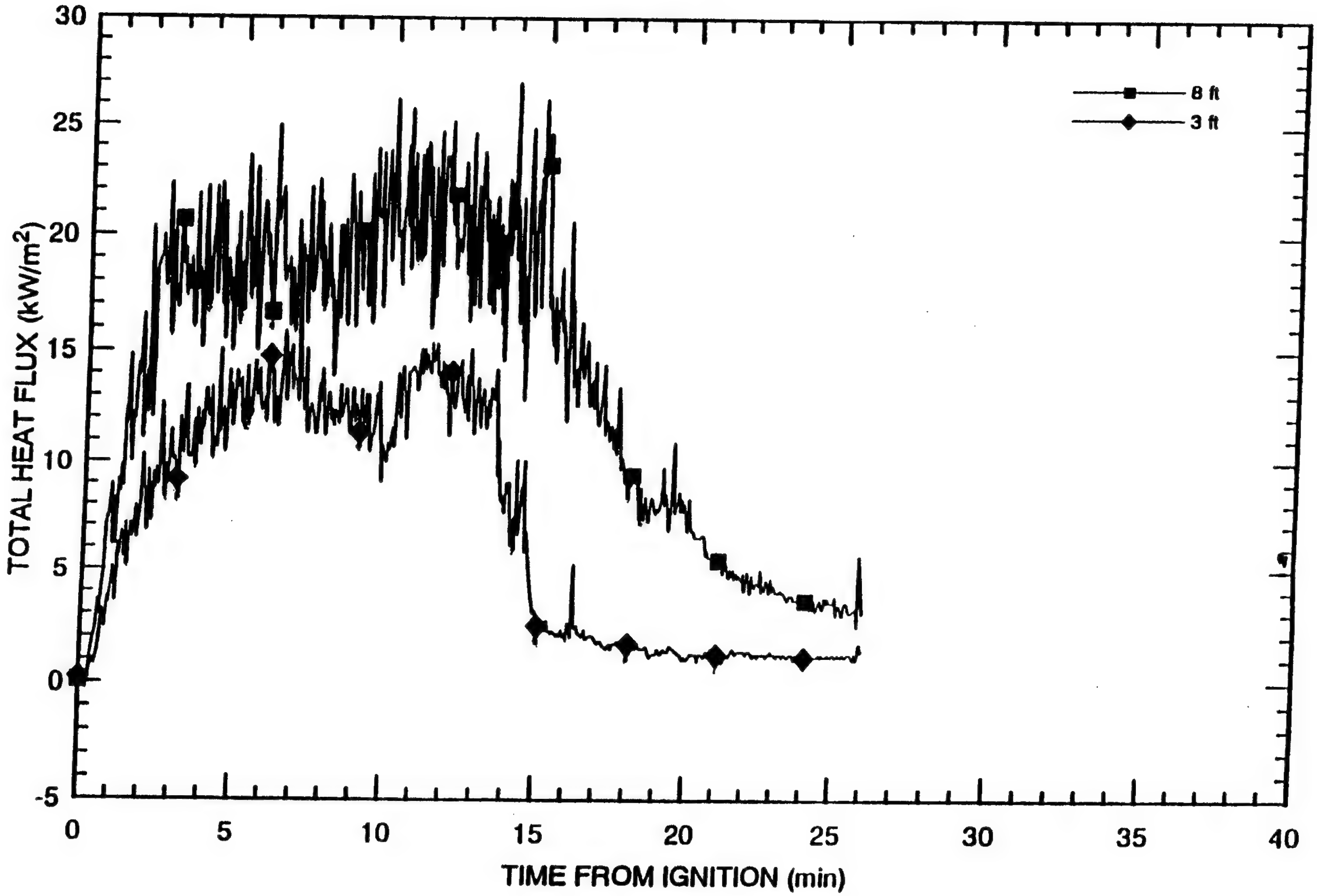


Fig. B117 - Burn room calorimeters for FOG_17

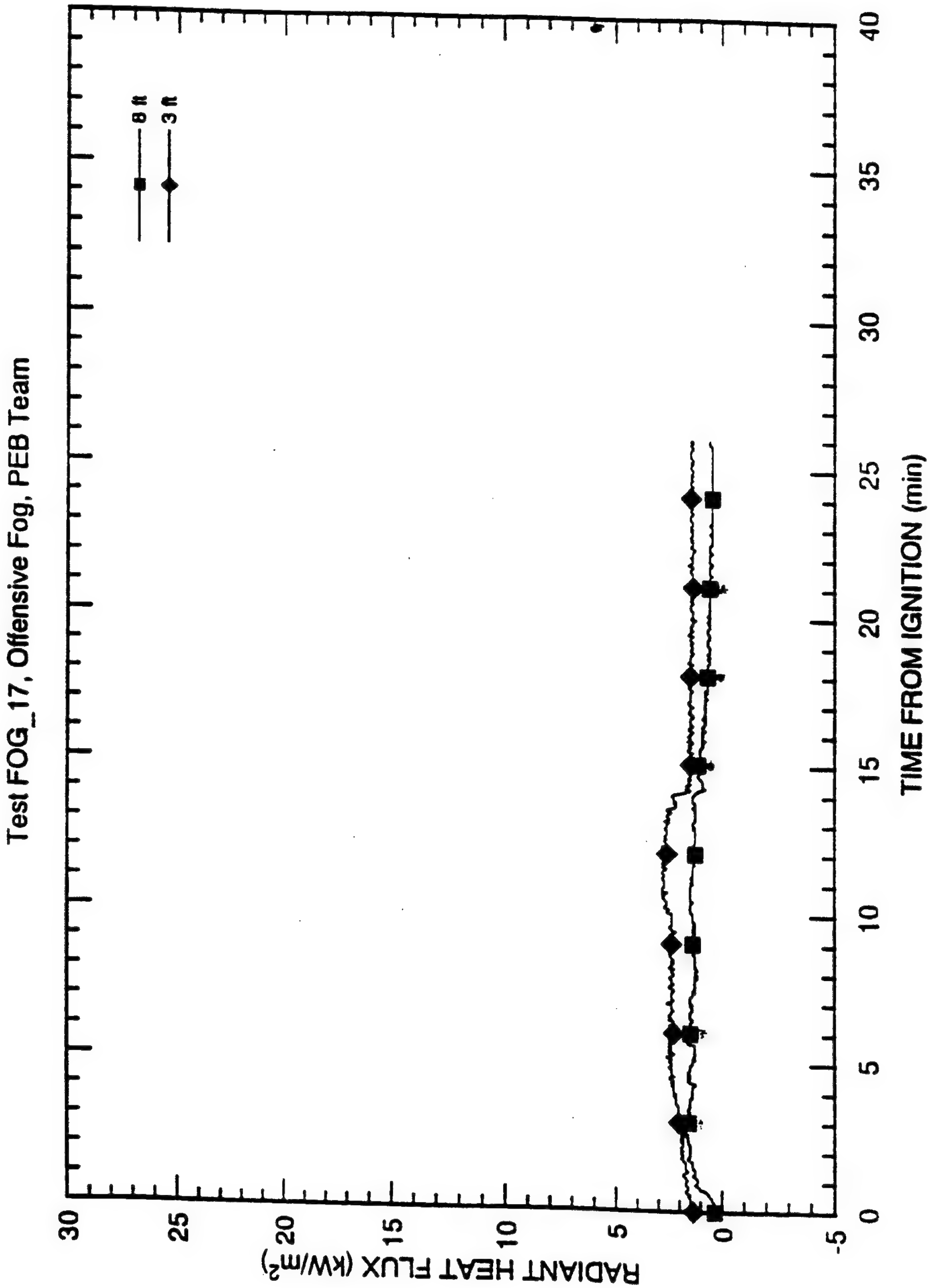


Fig. B118 - Burn room radiometers for FOG_17

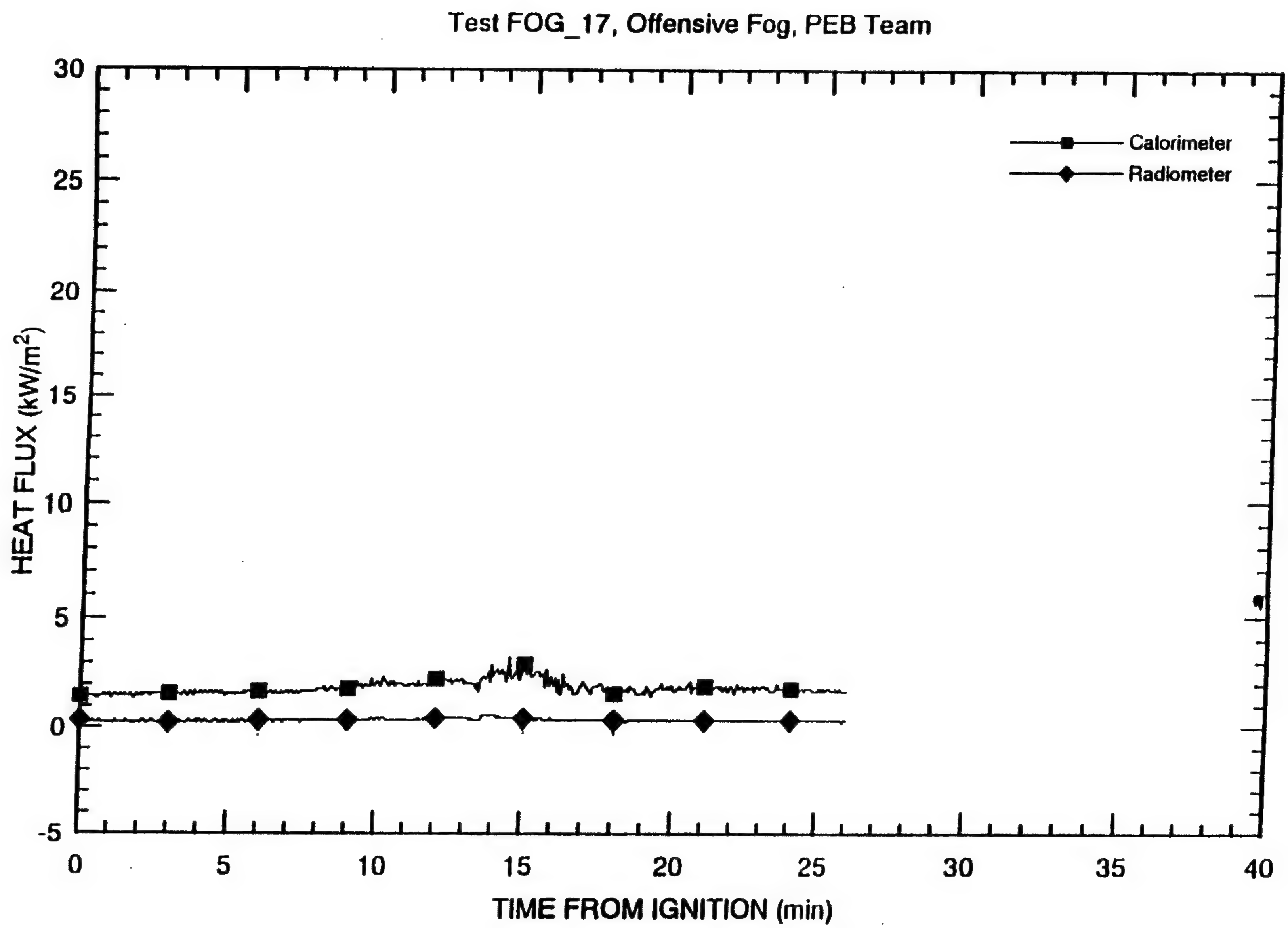


Fig. B119 - GSK radiometer and calorimeter for FOG_17

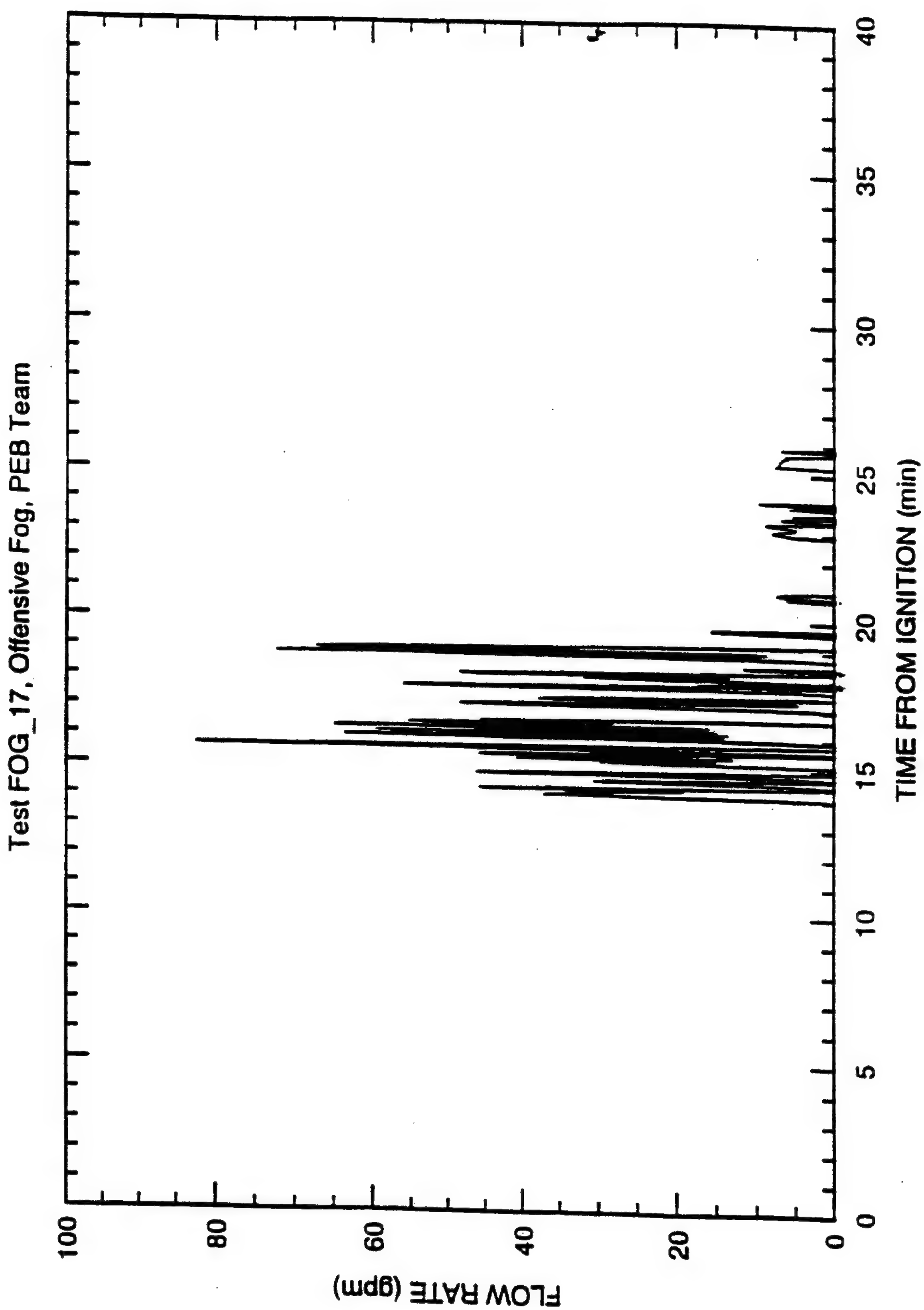


Fig. B120 - Water flow rate for FOG_17

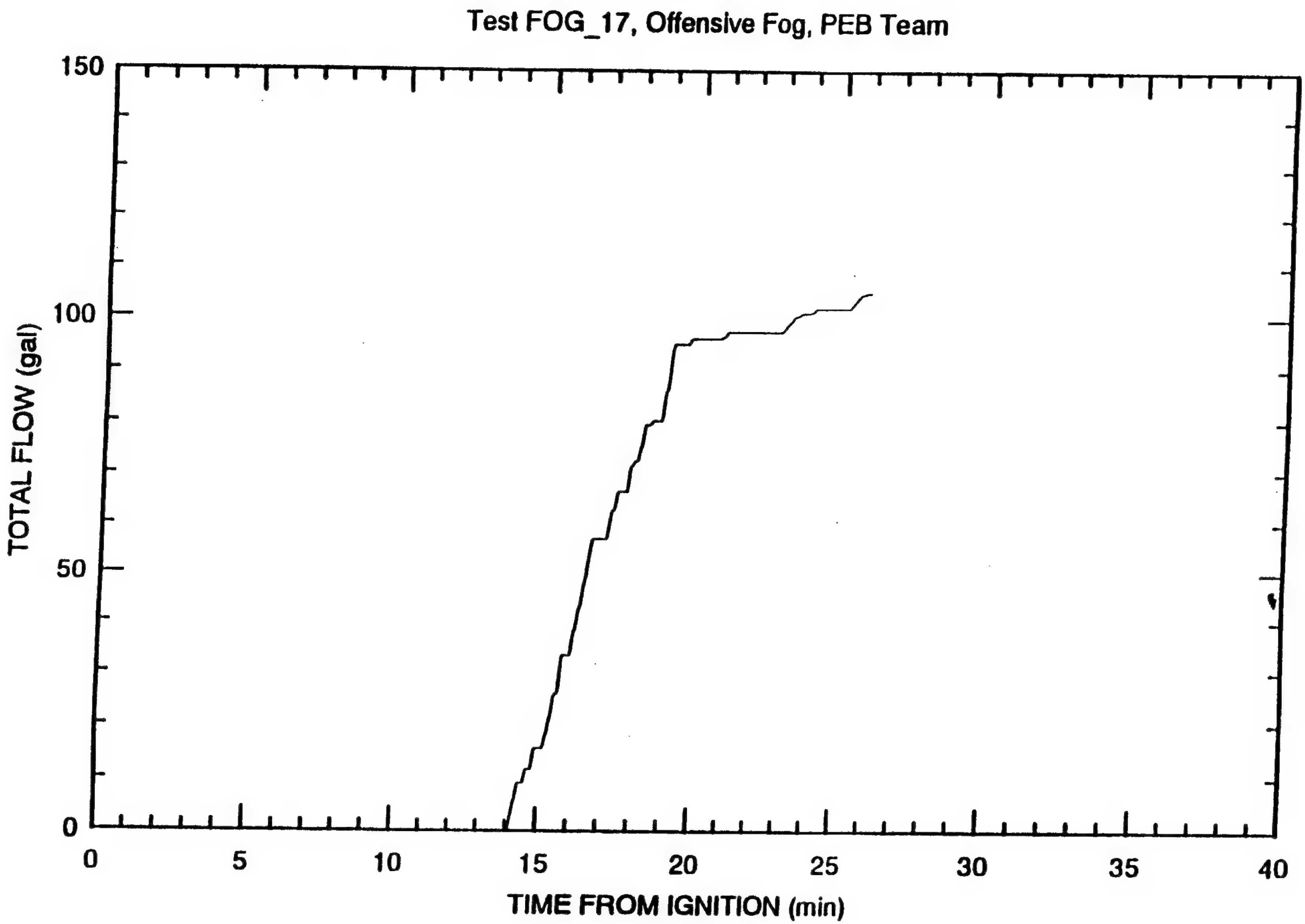


Fig. B121 - Cumulative water flow for FOG_17

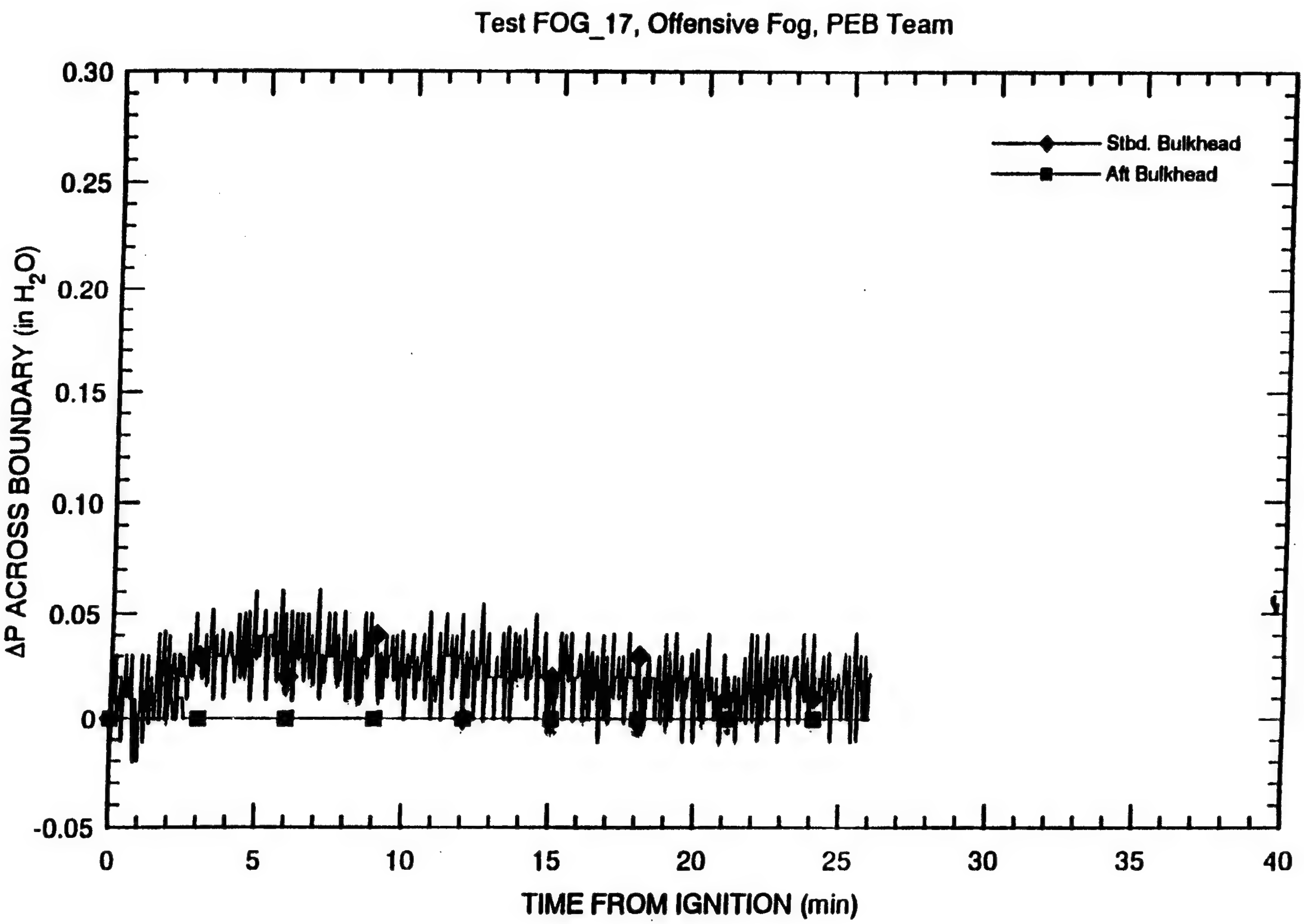


Fig. B122 - Pressure differential across burn room boundaries for FOG_17

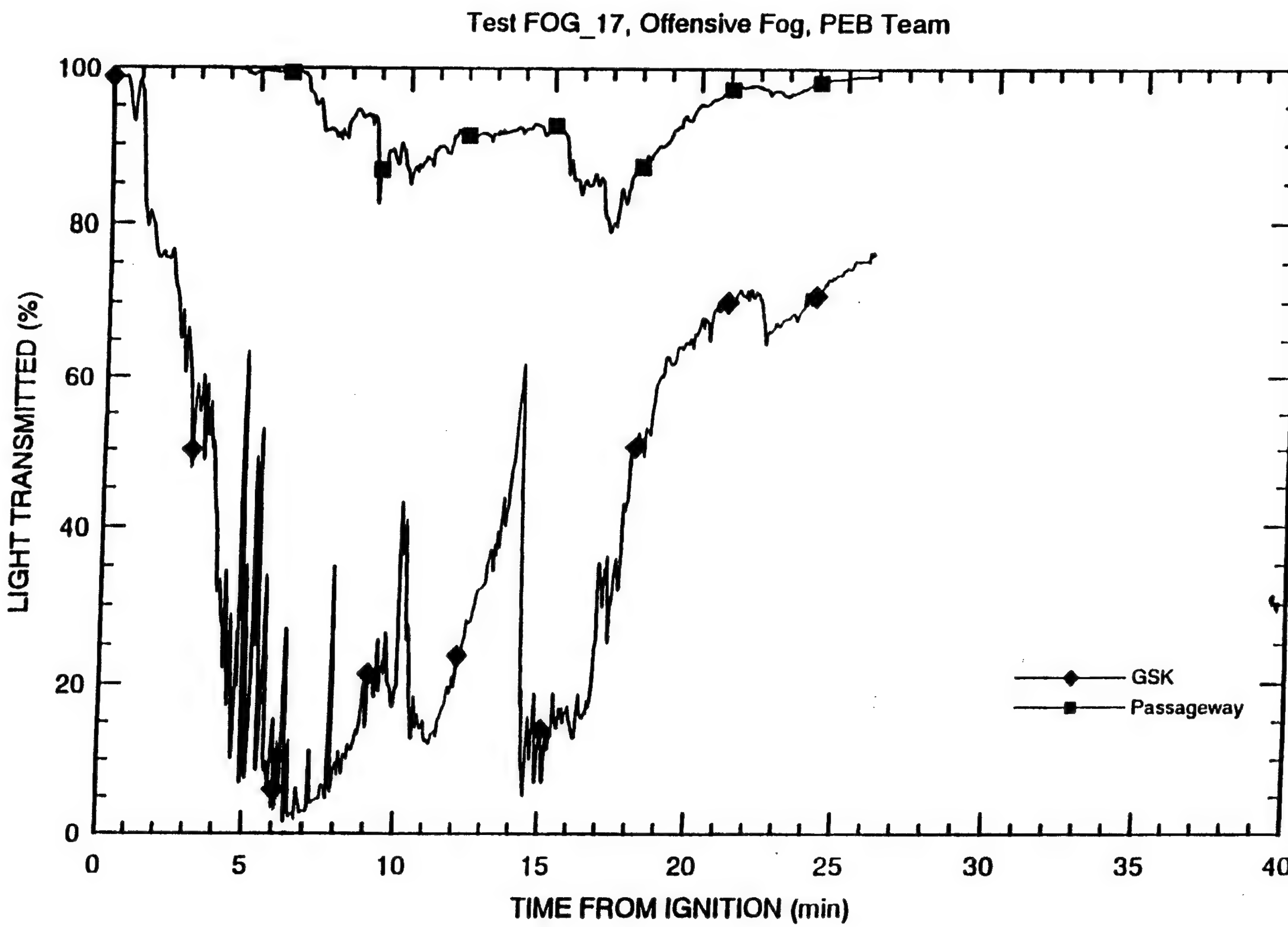


Fig. B123 - Smoke Obscuration for FOG_17

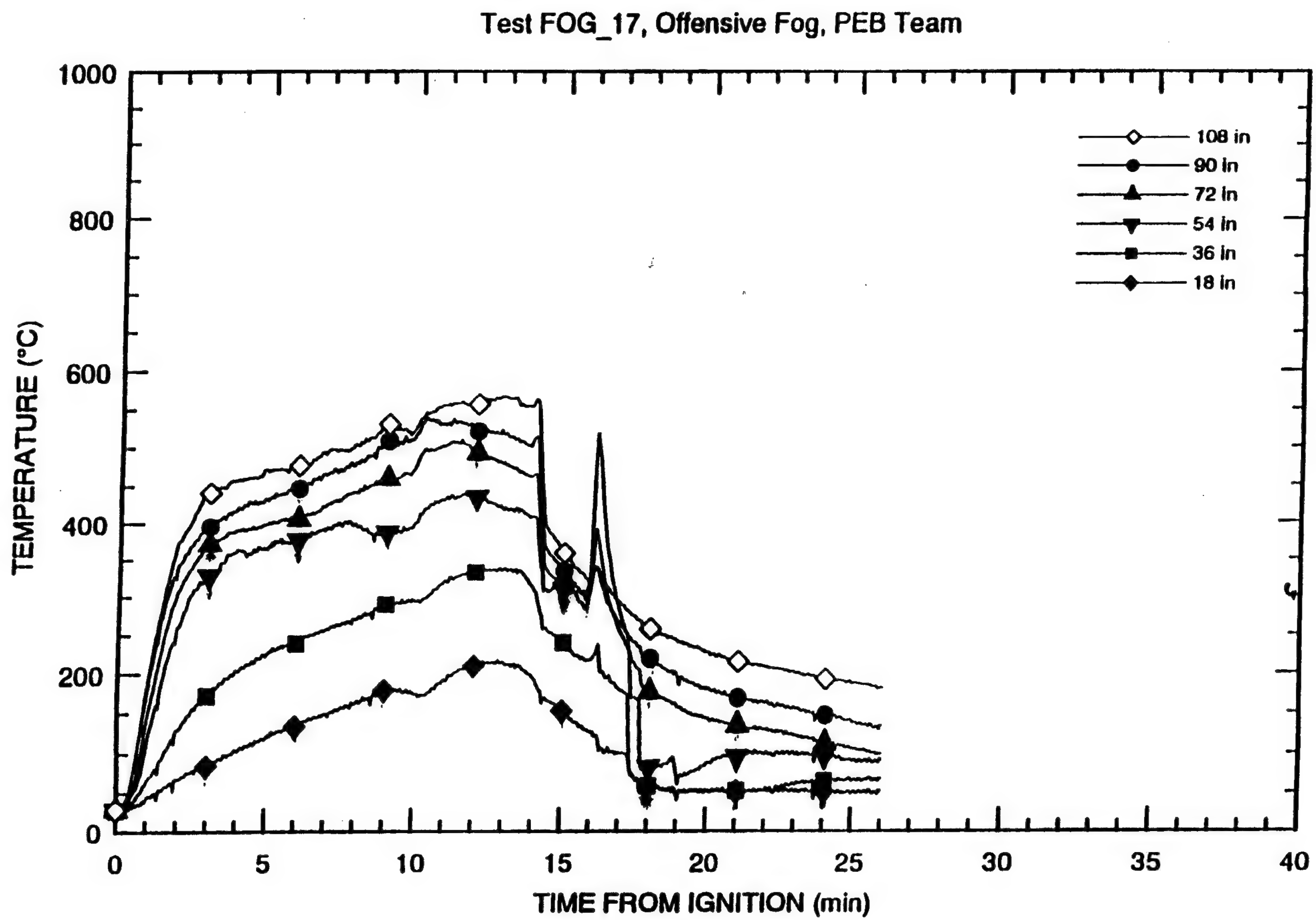


Fig. B124 - Port outer (2-18-2) thermocouple tree for FOG_17

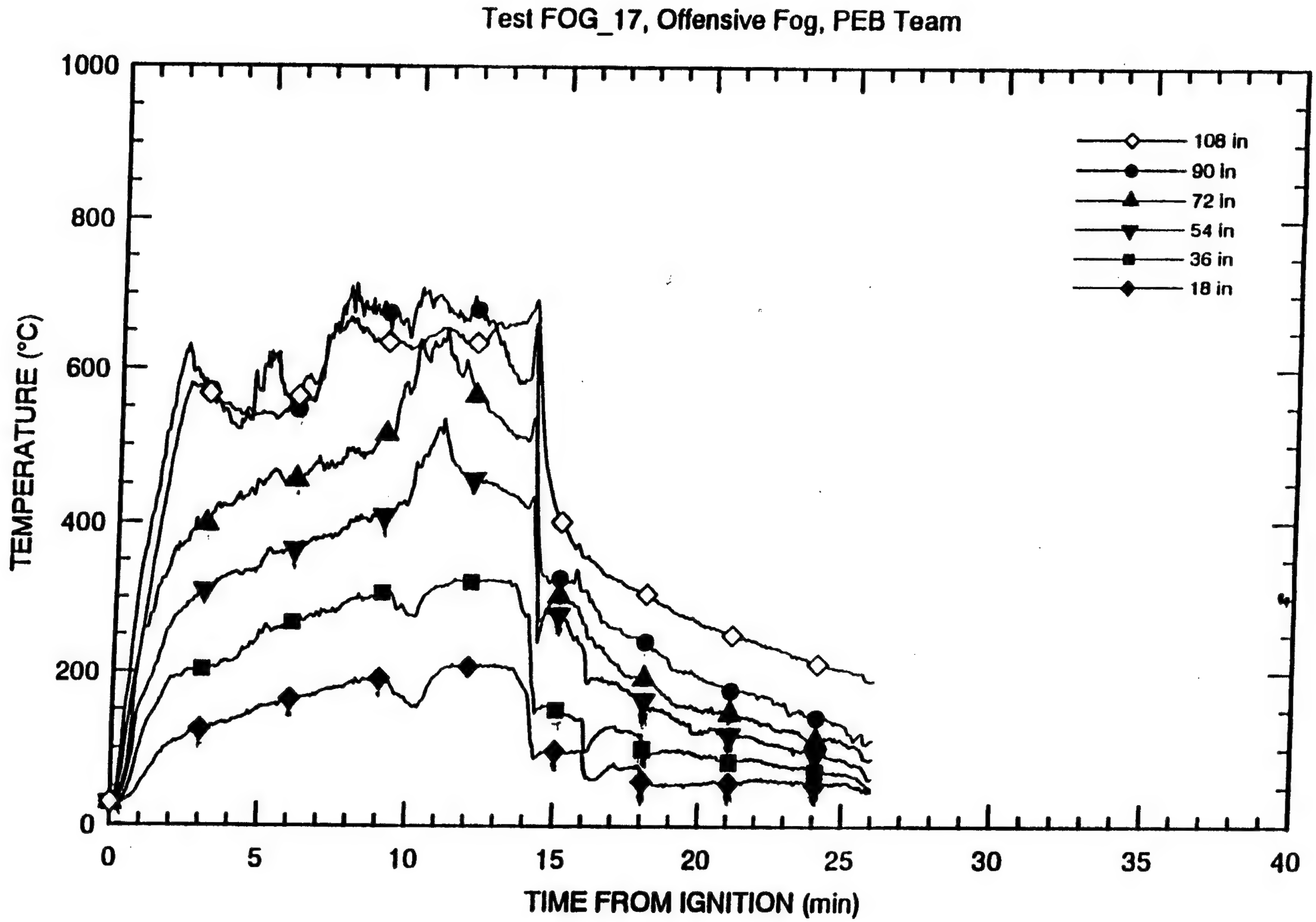


Fig. B125 - Port inner (2-19-0) thermocouple tree for FOG_17

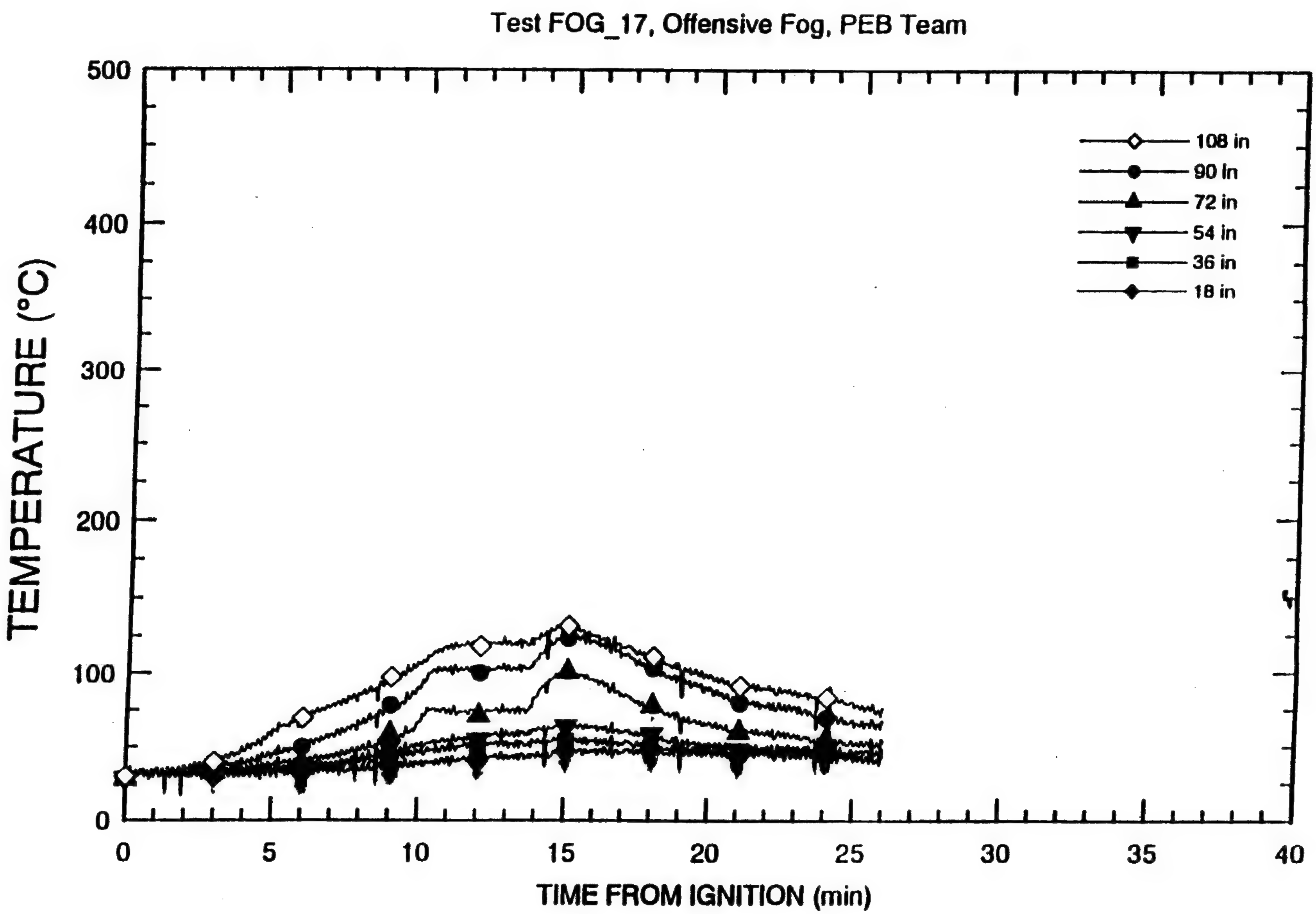


Fig. B126 - Starboard outer (2-21-3) thermocouple tree for FOG_17

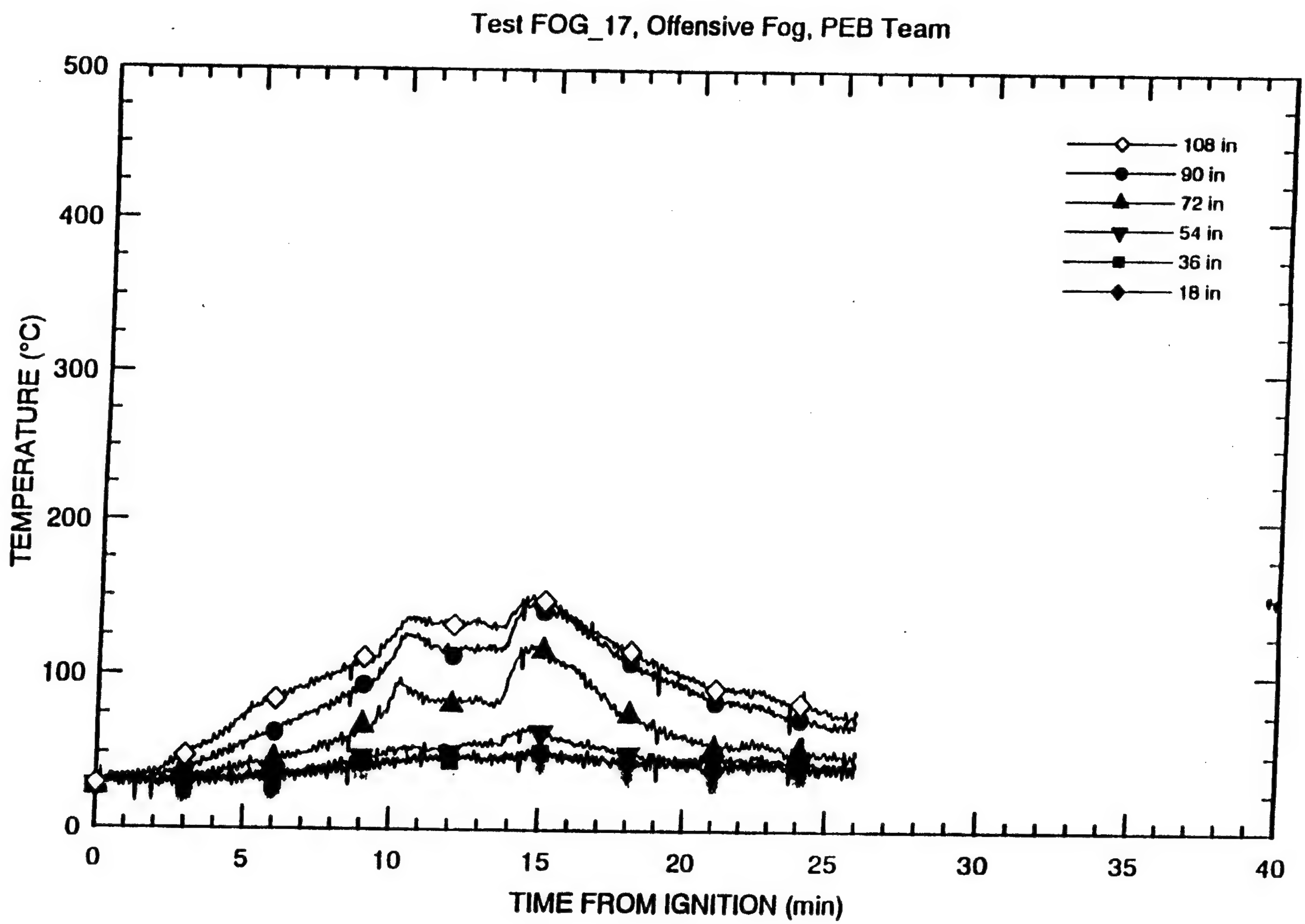


Fig. B127 - Starboard inner (2-21-1) thermocouple tree for FOG_17

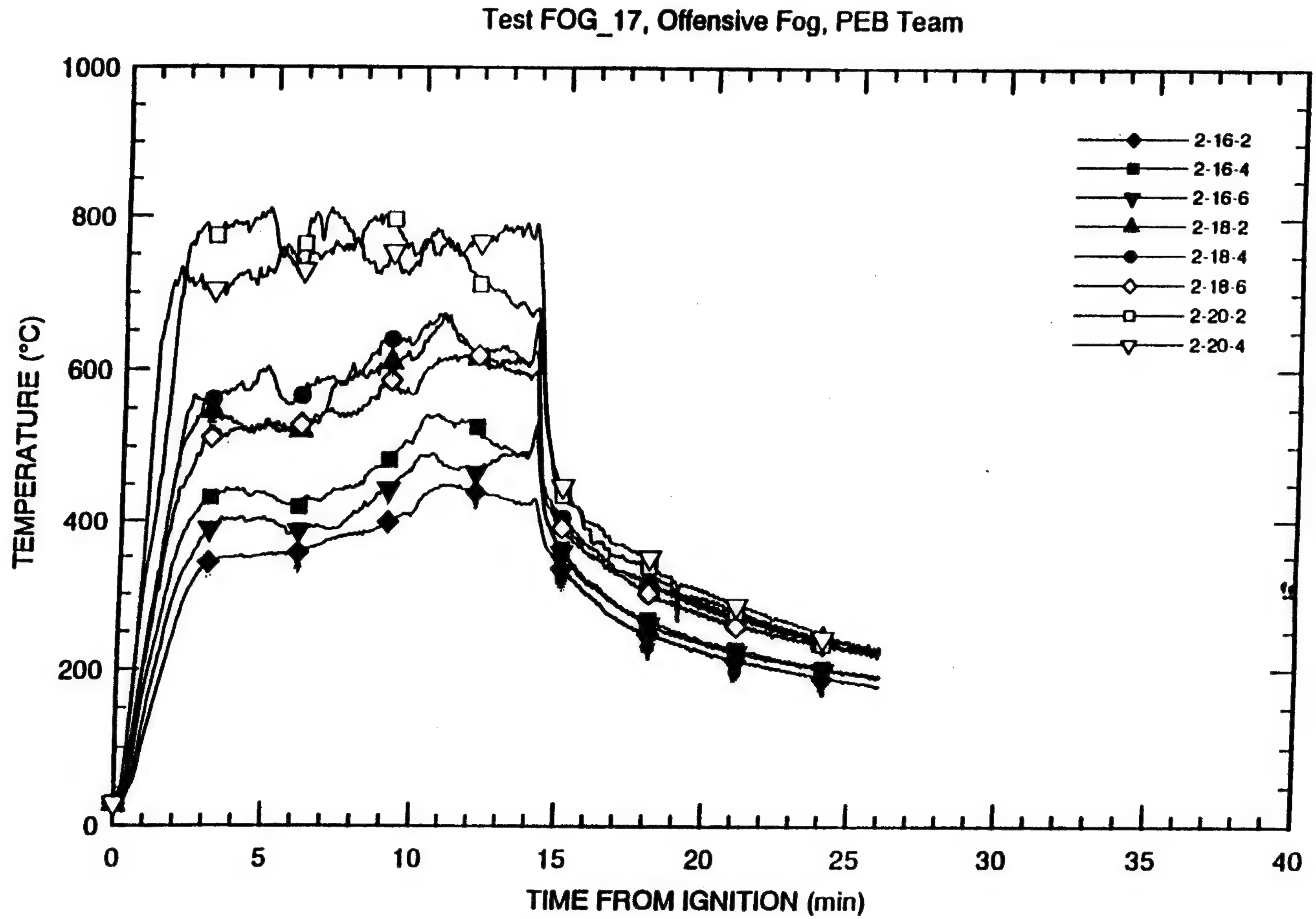


Fig. B128 - Burn room overhead temperatures for FOG_17

Test FOG_17, Offensive Fog, PEB Team

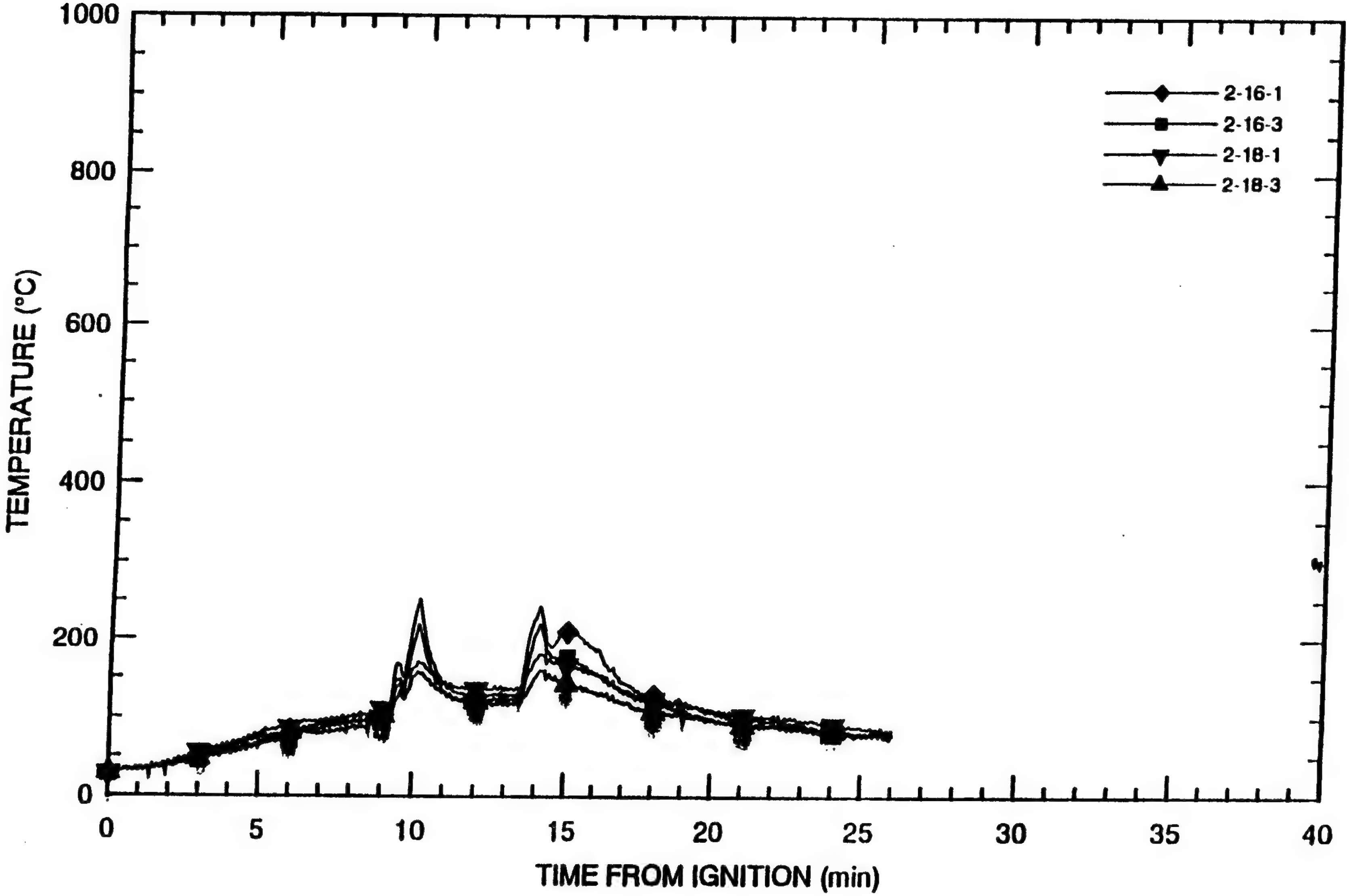


Fig. B129 - GSK overhead temperatures for FOG_17

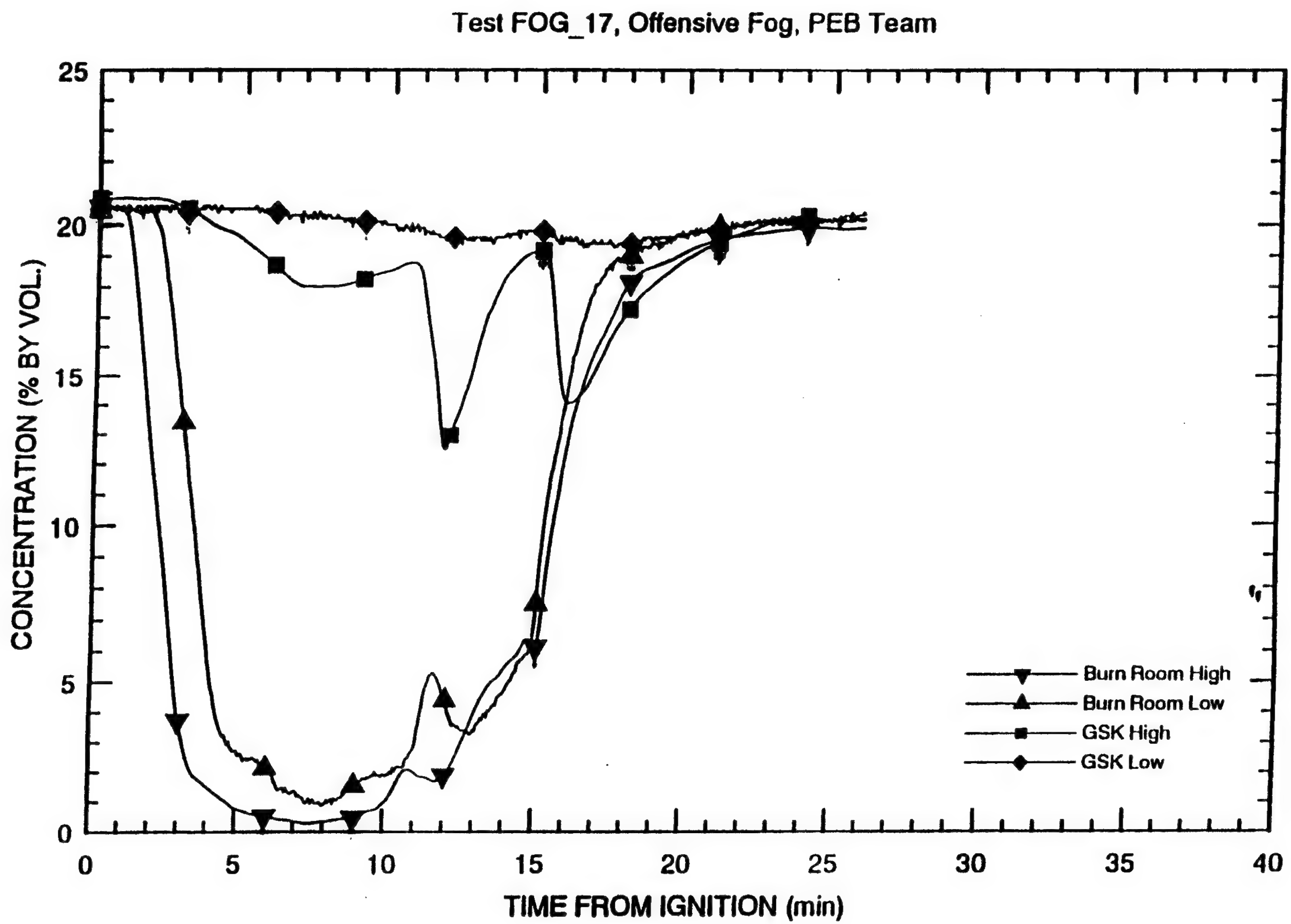


Fig. B130 - Oxygen (O_2) concentrations for FOG_17

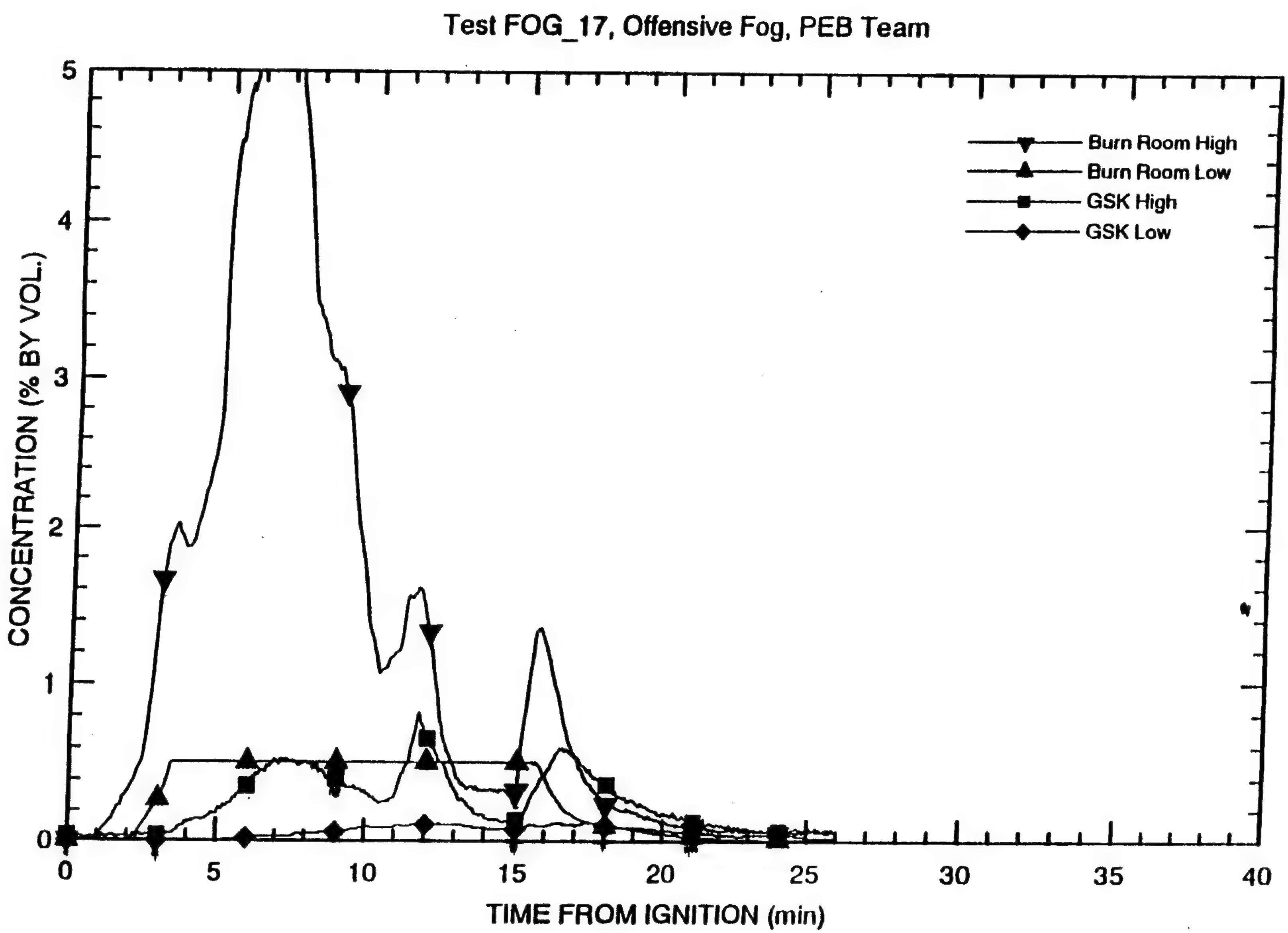


Fig. B131 - Carbon monoxide (CO) concentrations for FOG_17

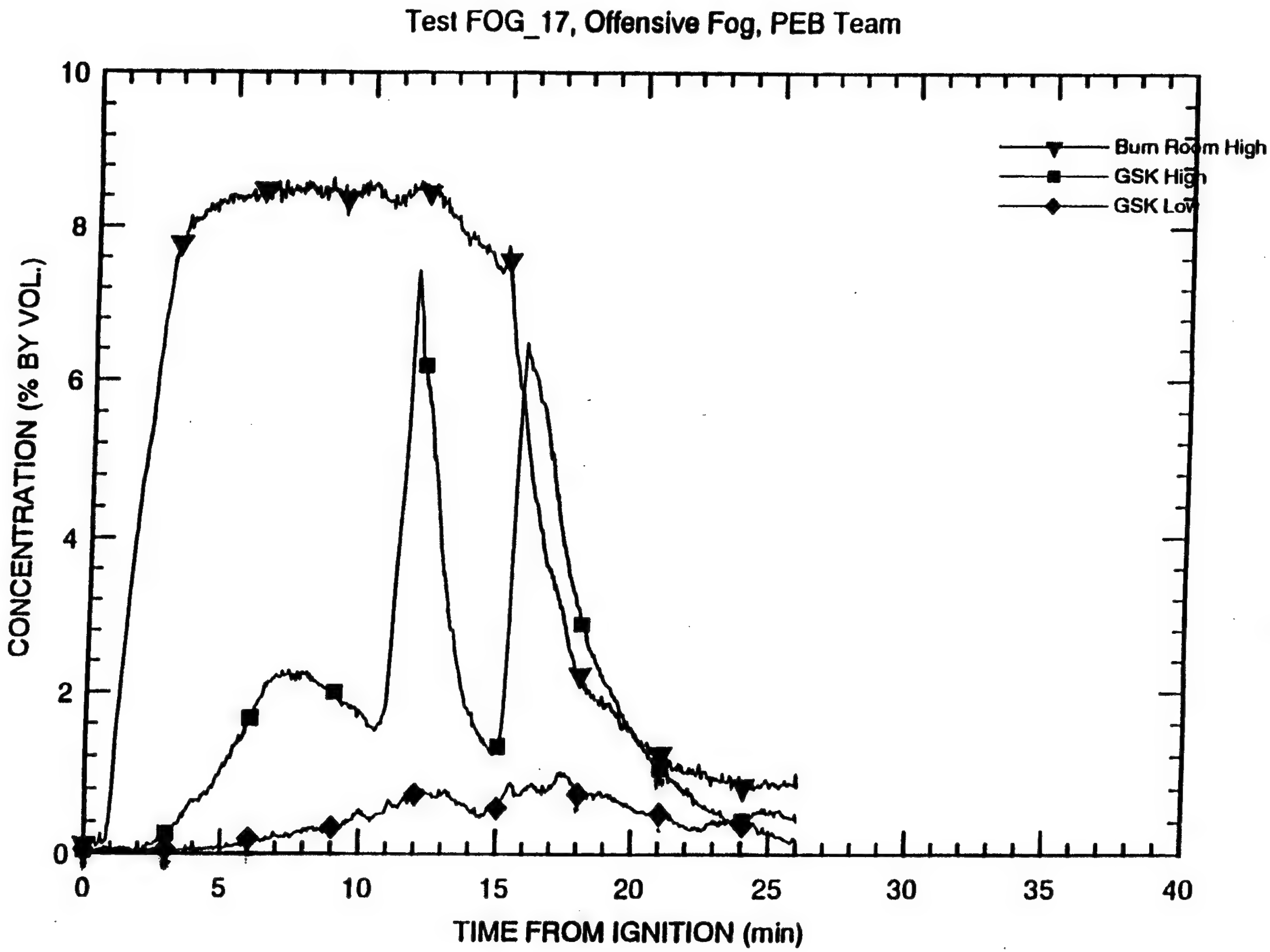


Fig. B132 - Carbon dioxide (CO_2) concentrations for FOG_17

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

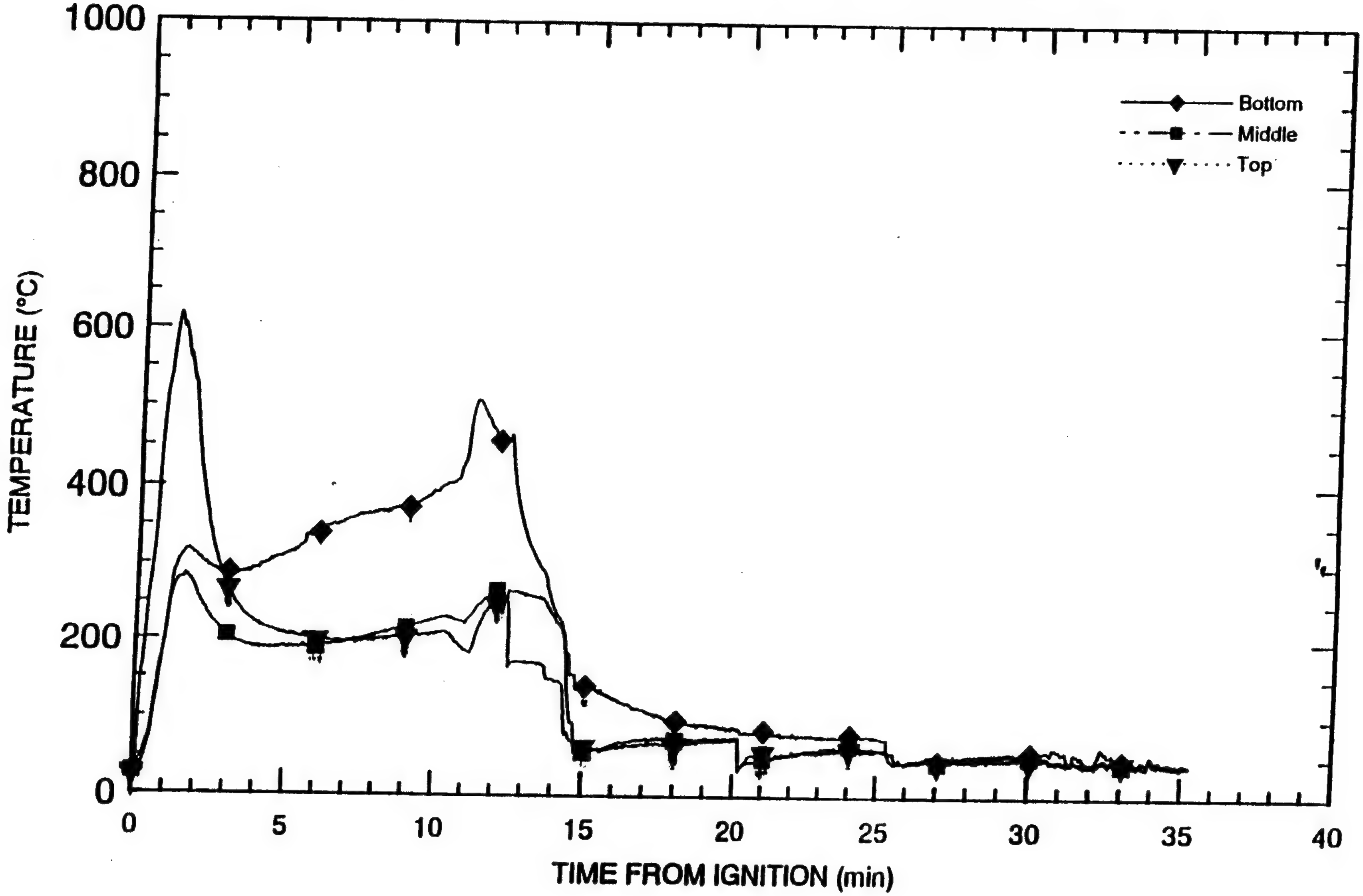


Fig. B133 - Wood crib #1 thermocouples for FOG_18

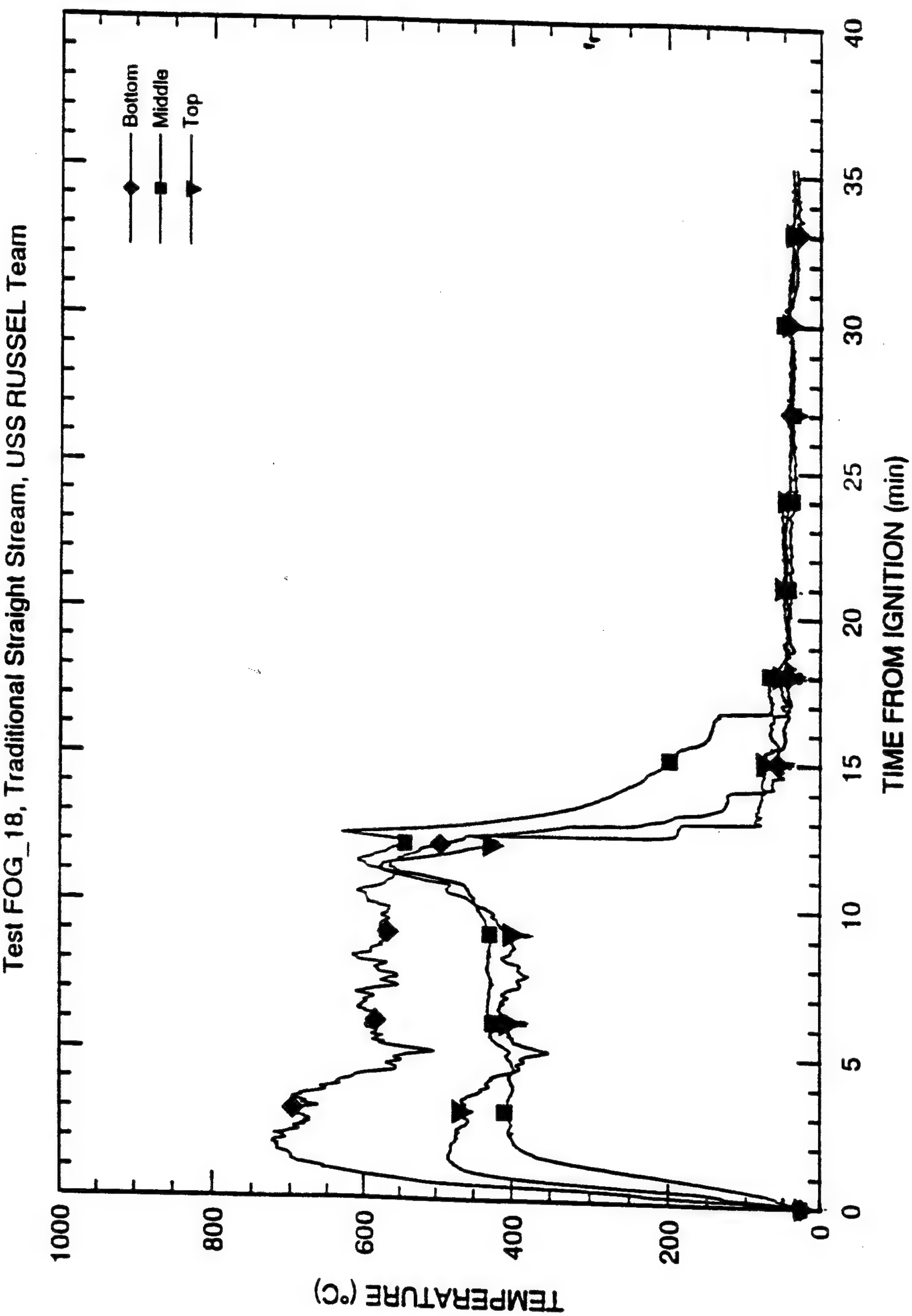


Fig. B134 - Wood crib #2 thermocouples for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

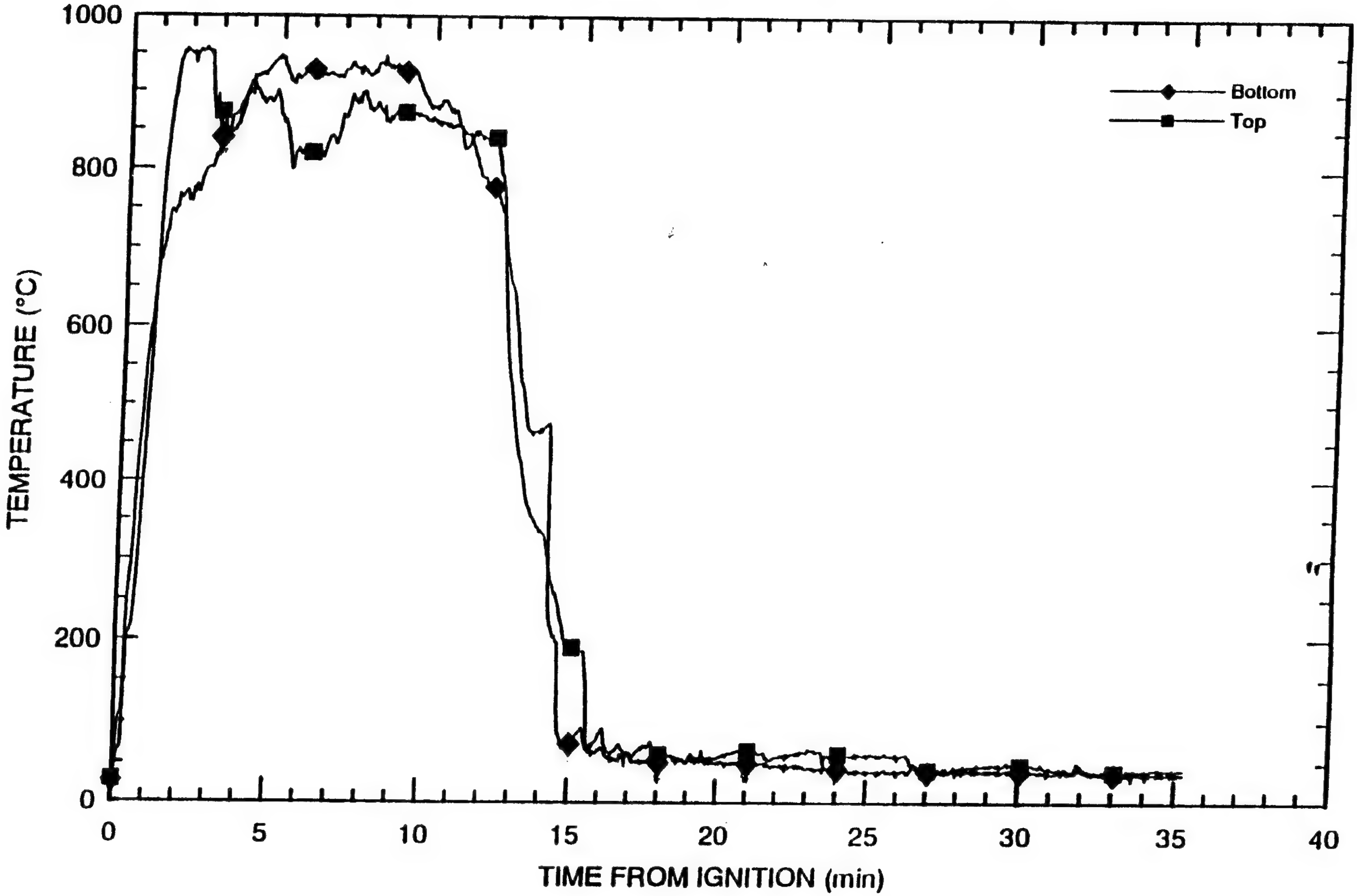


Fig. B135 - Wood crib #3 thermocouples for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

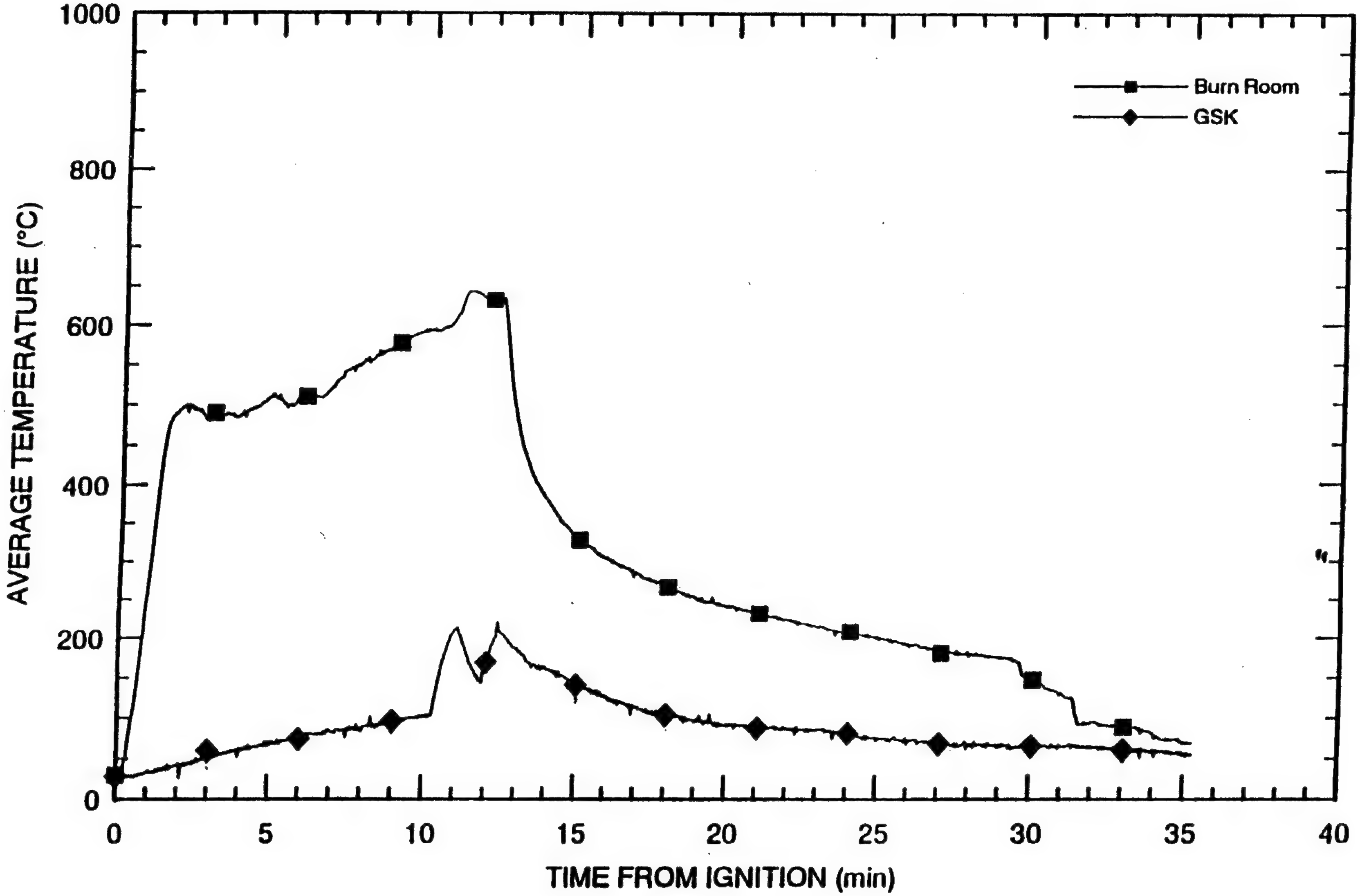


Fig. B136 - Average of overhead thermocouples for FOG_18

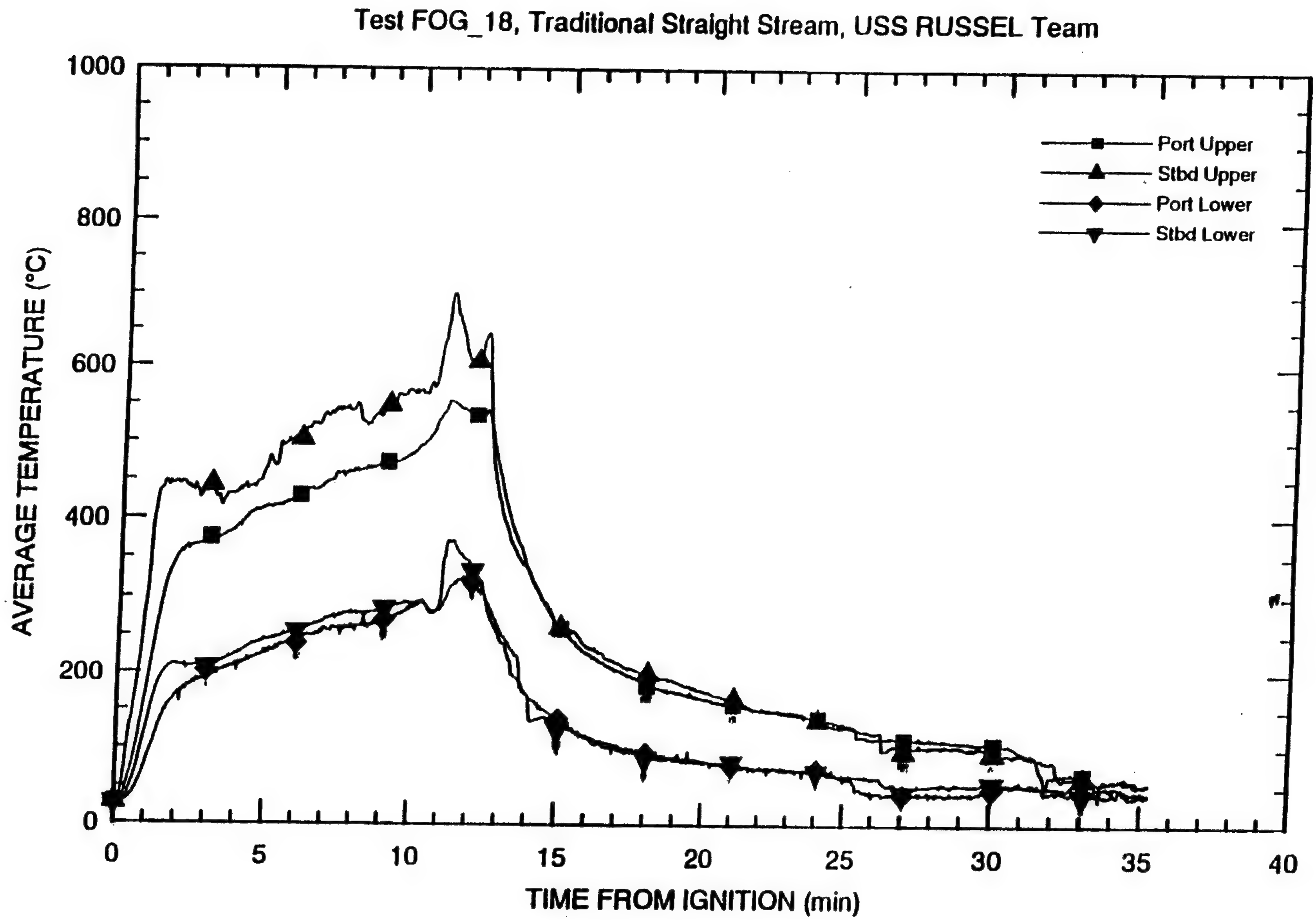


Fig. B137 - Burn room thermocouple string averages (upper vs. lower) for FOG_18

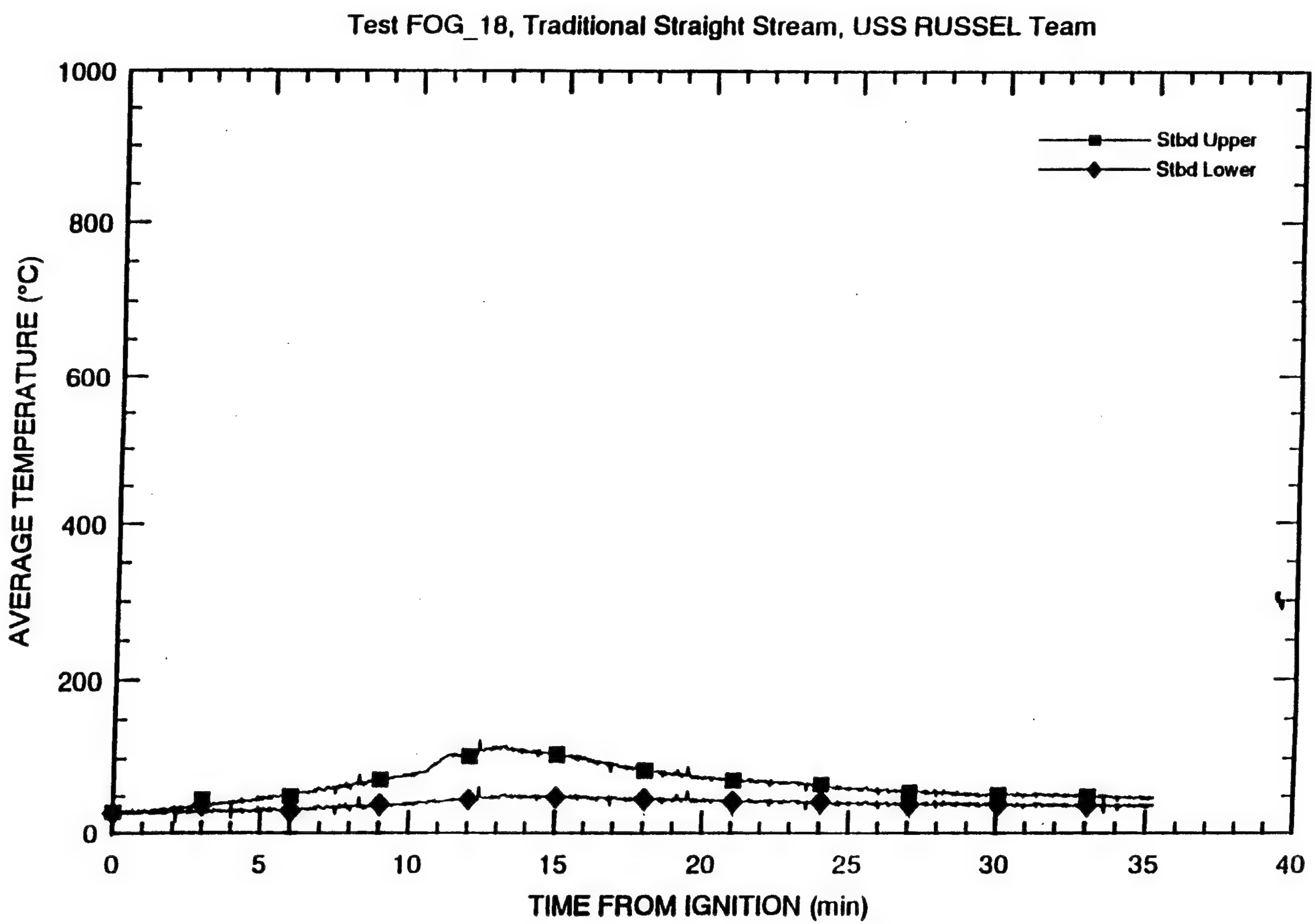


Fig. B138 - GSK thermocouple string averages (upper vs. lower) for FOG_18

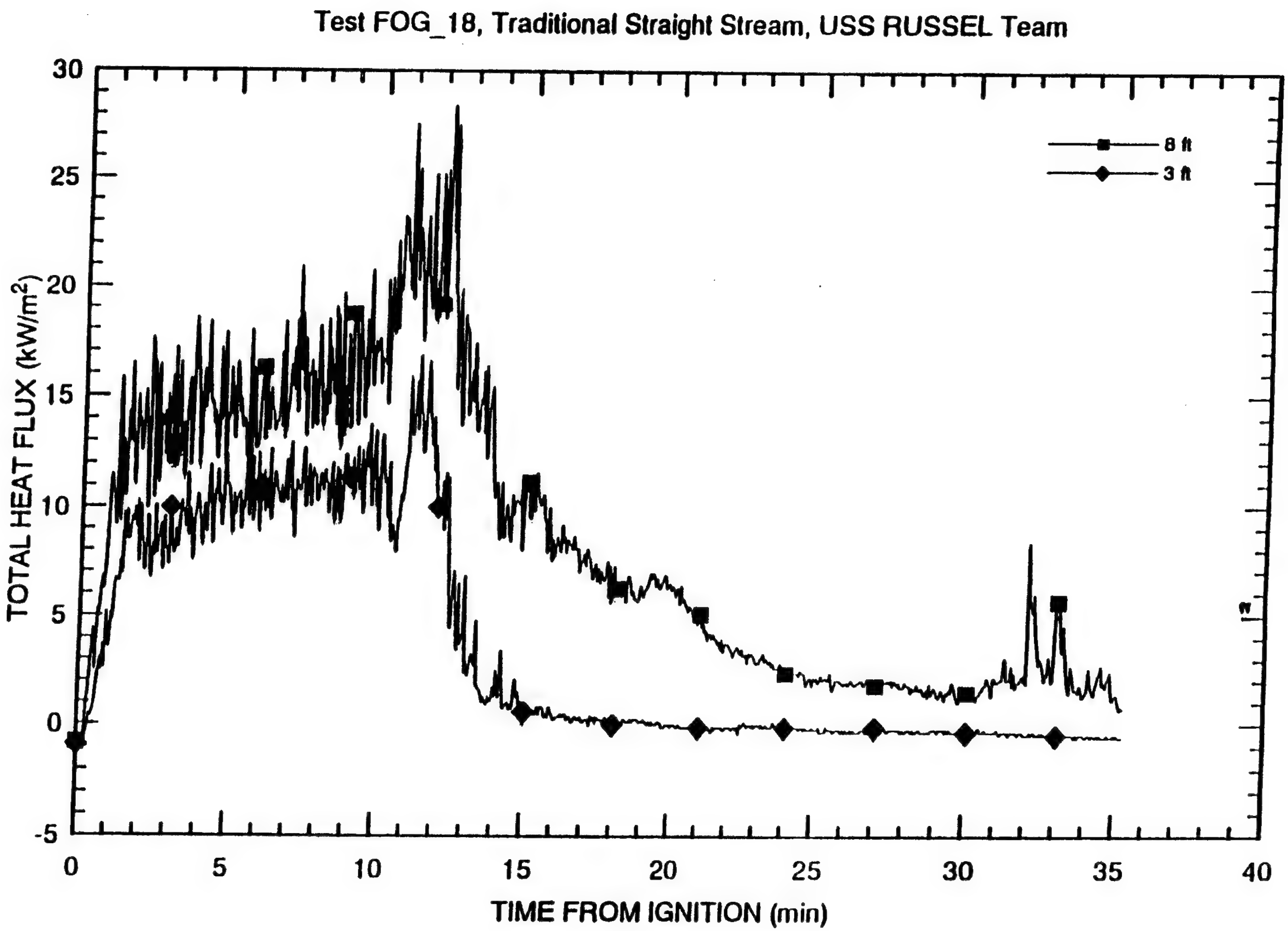


Fig. B139 - Burn room calorimeters for FOG_18

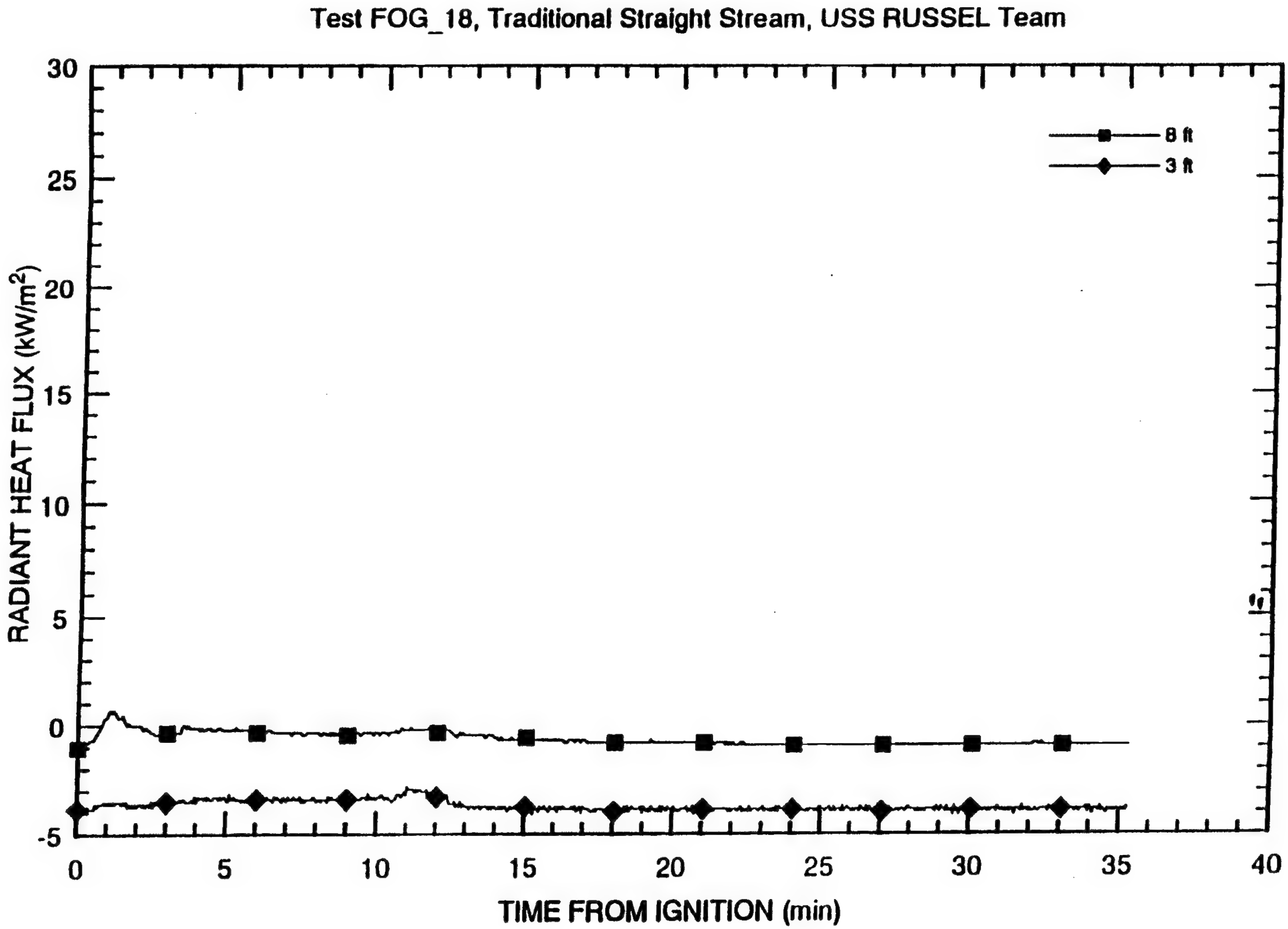


Fig. B140 - Burn room radiometers for FOG_18

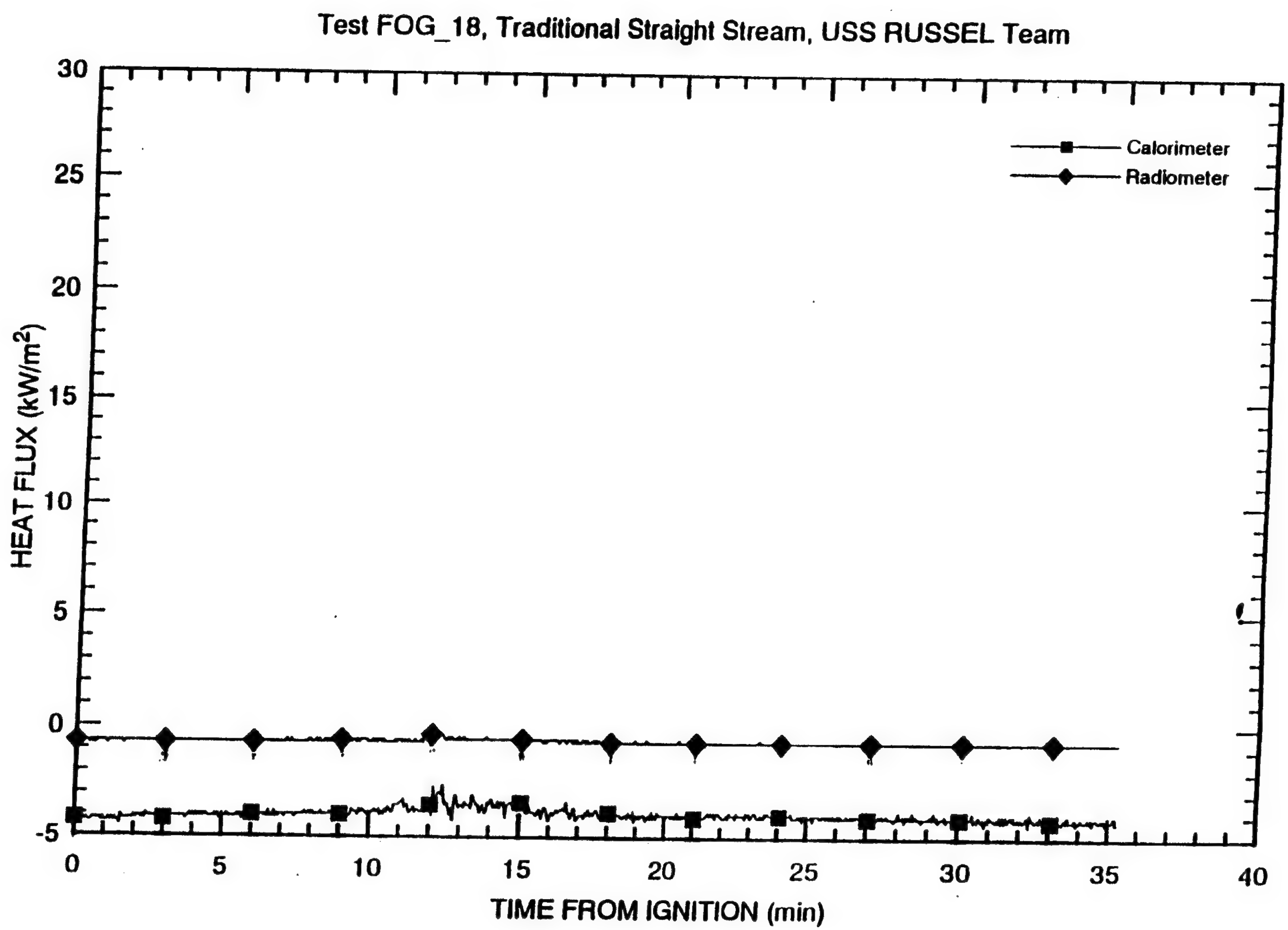


Fig. B141 - GSK radiometer and calorimeter for FOG_18

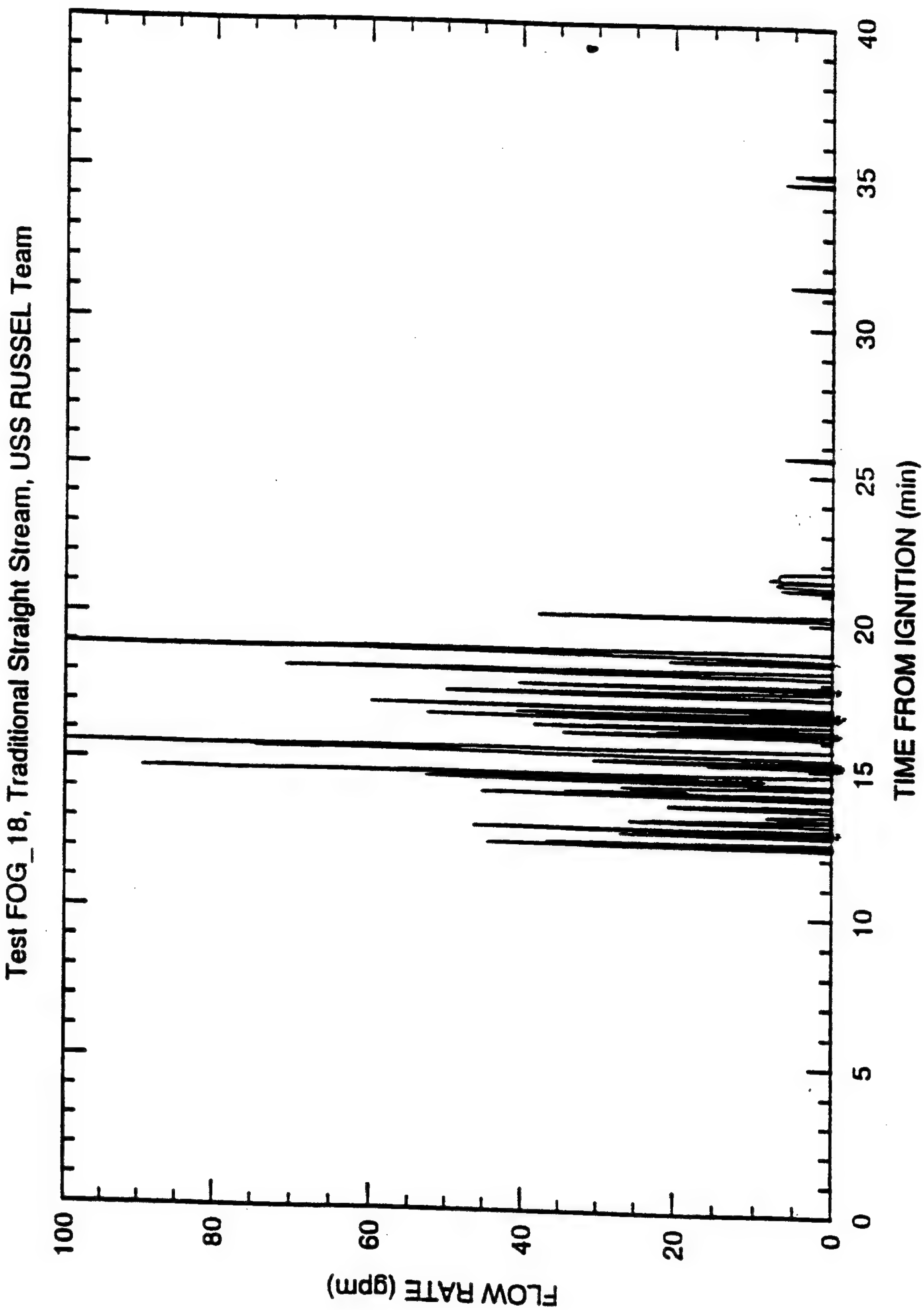


Fig. B142 - Water flow rate for FOG_18

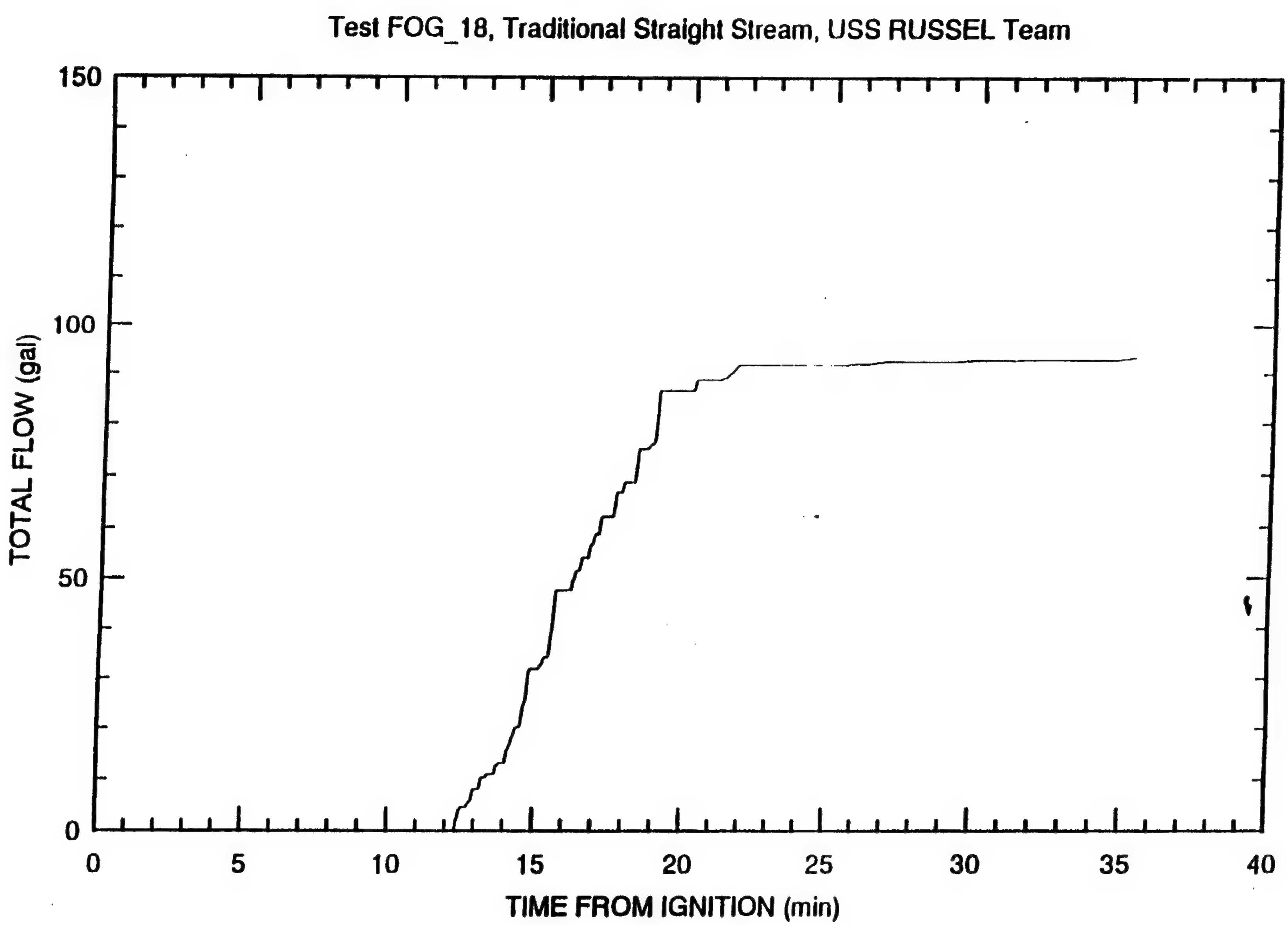


Fig. B143 - Cumulative water flow for FOG_18

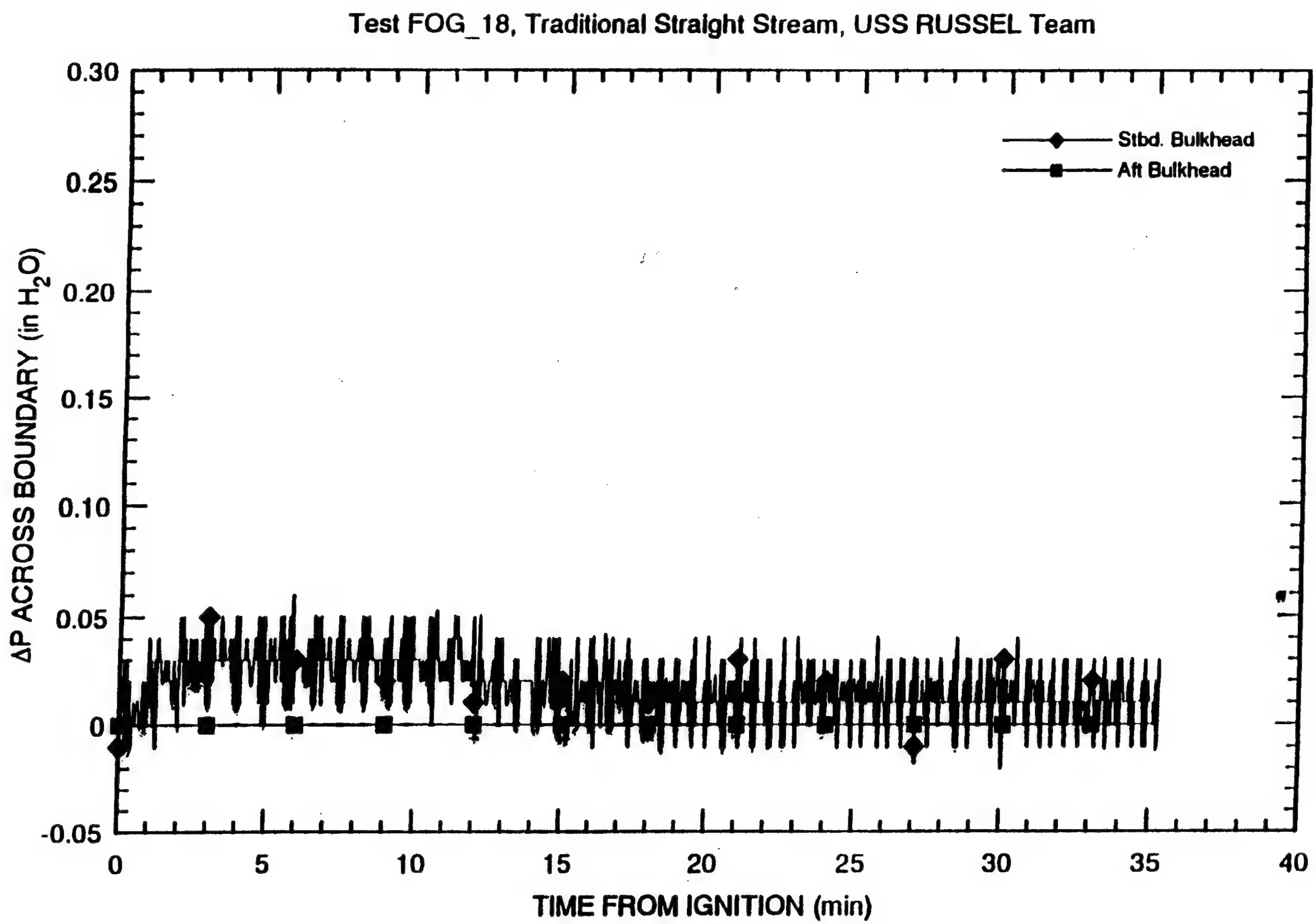


Fig. B144 - Pressure differential across burn room boundaries for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

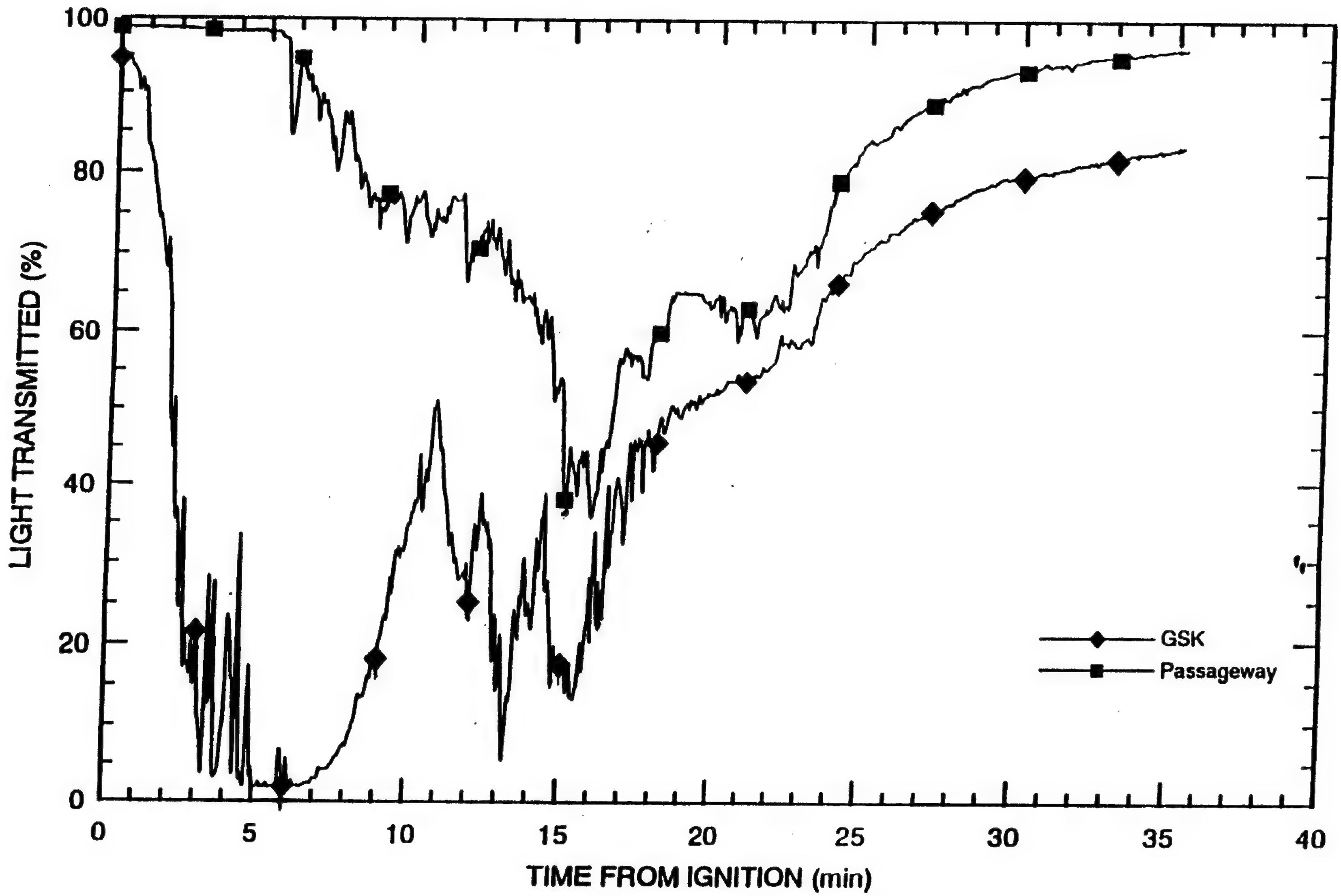


Fig. B145 - Smoke Obscuration for FOG_18

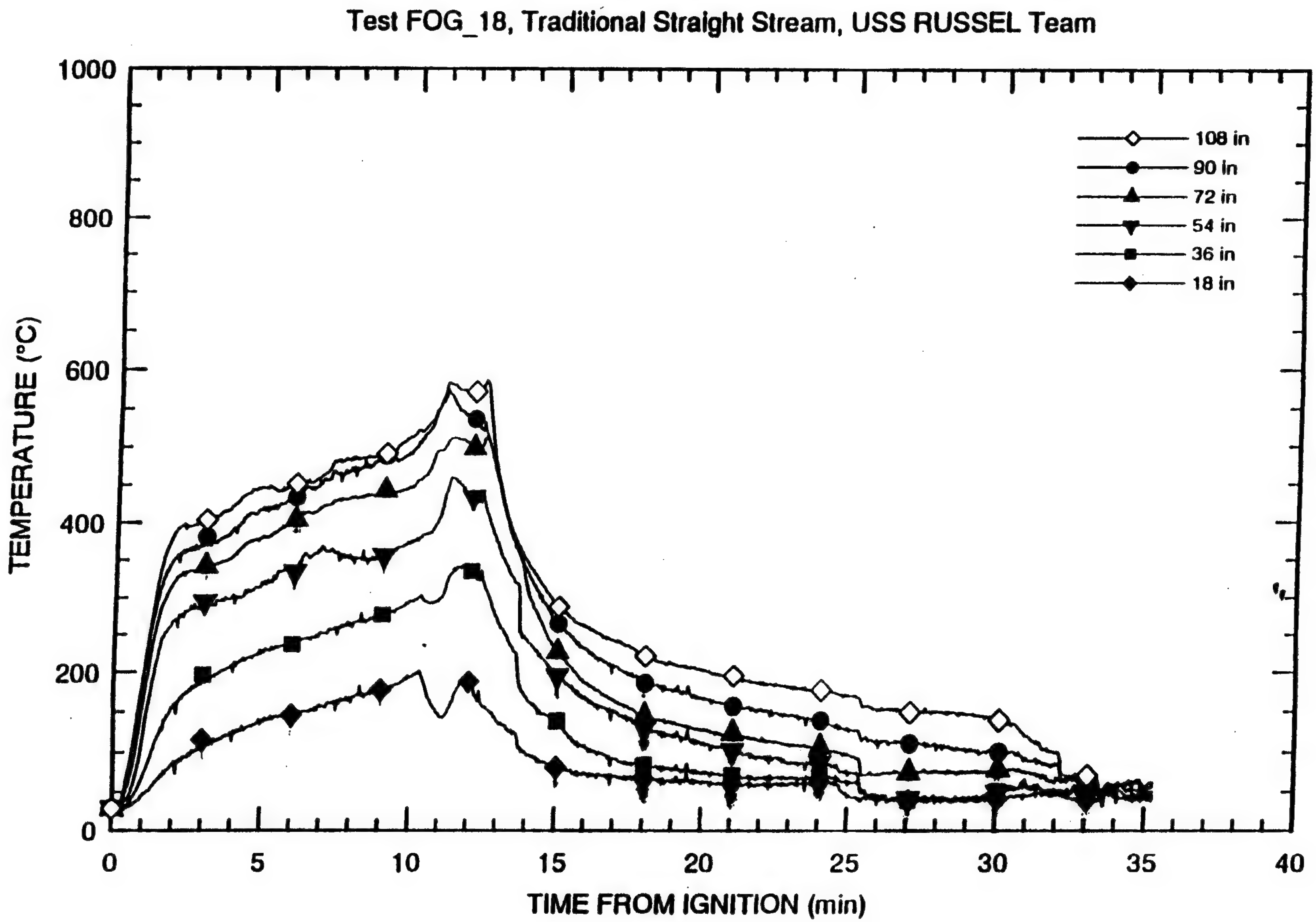


Fig. B146 - Port outer (2-18-2) thermocouple tree for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

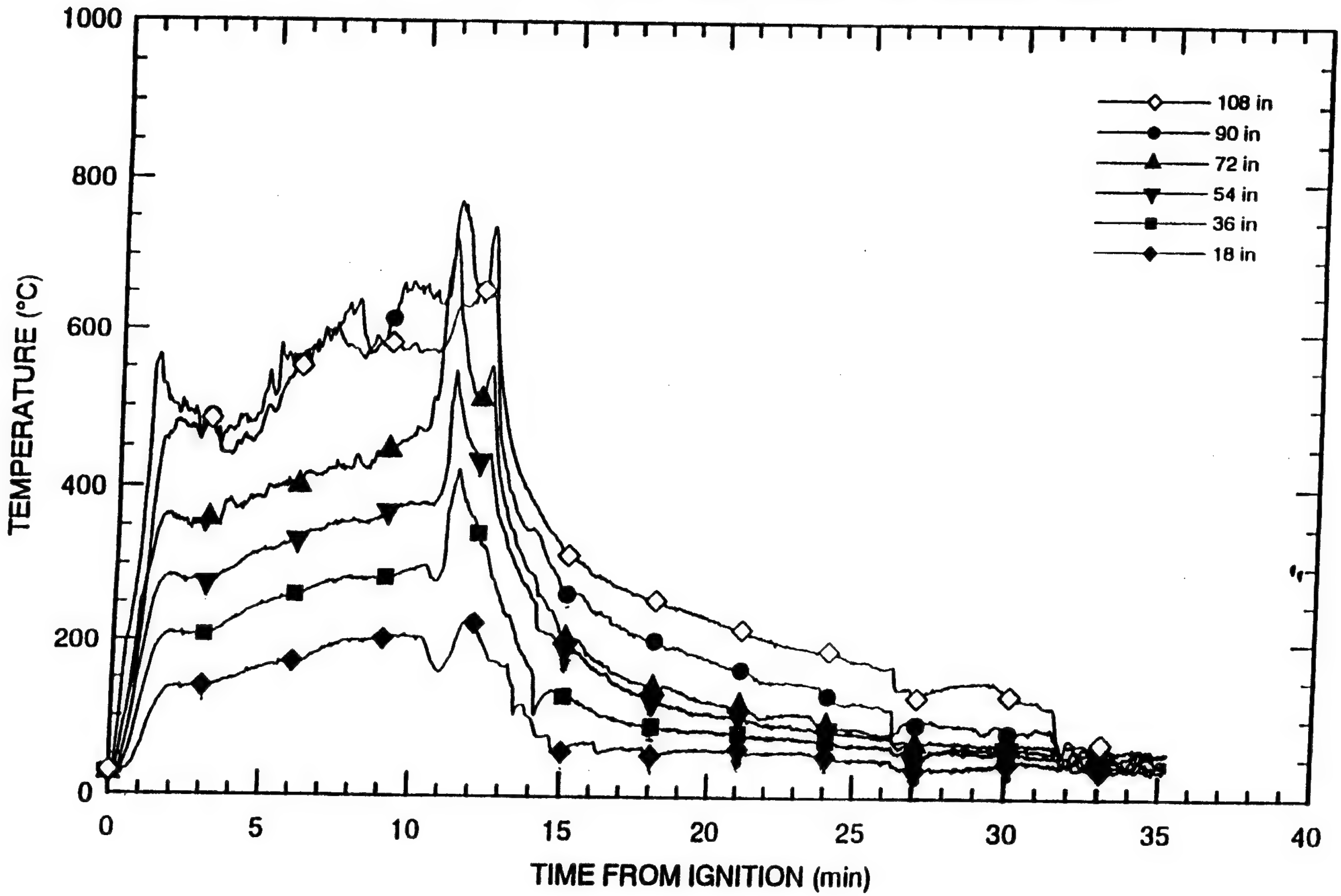


Fig. B147 - Port inner (2-19-0) thermocouple tree for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

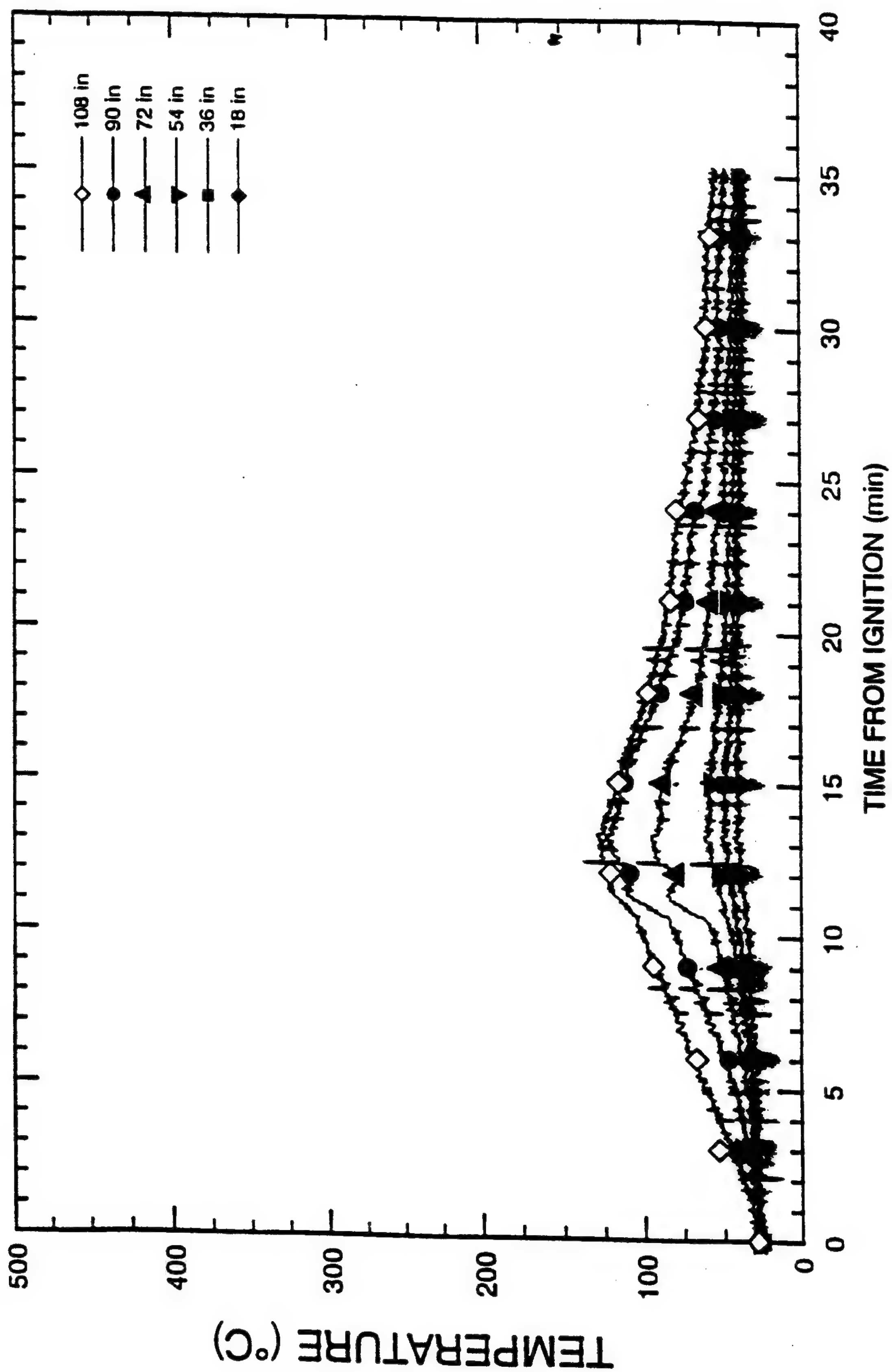


Fig. B148 - Starboard outer (2-21-3) thermocouple tree for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

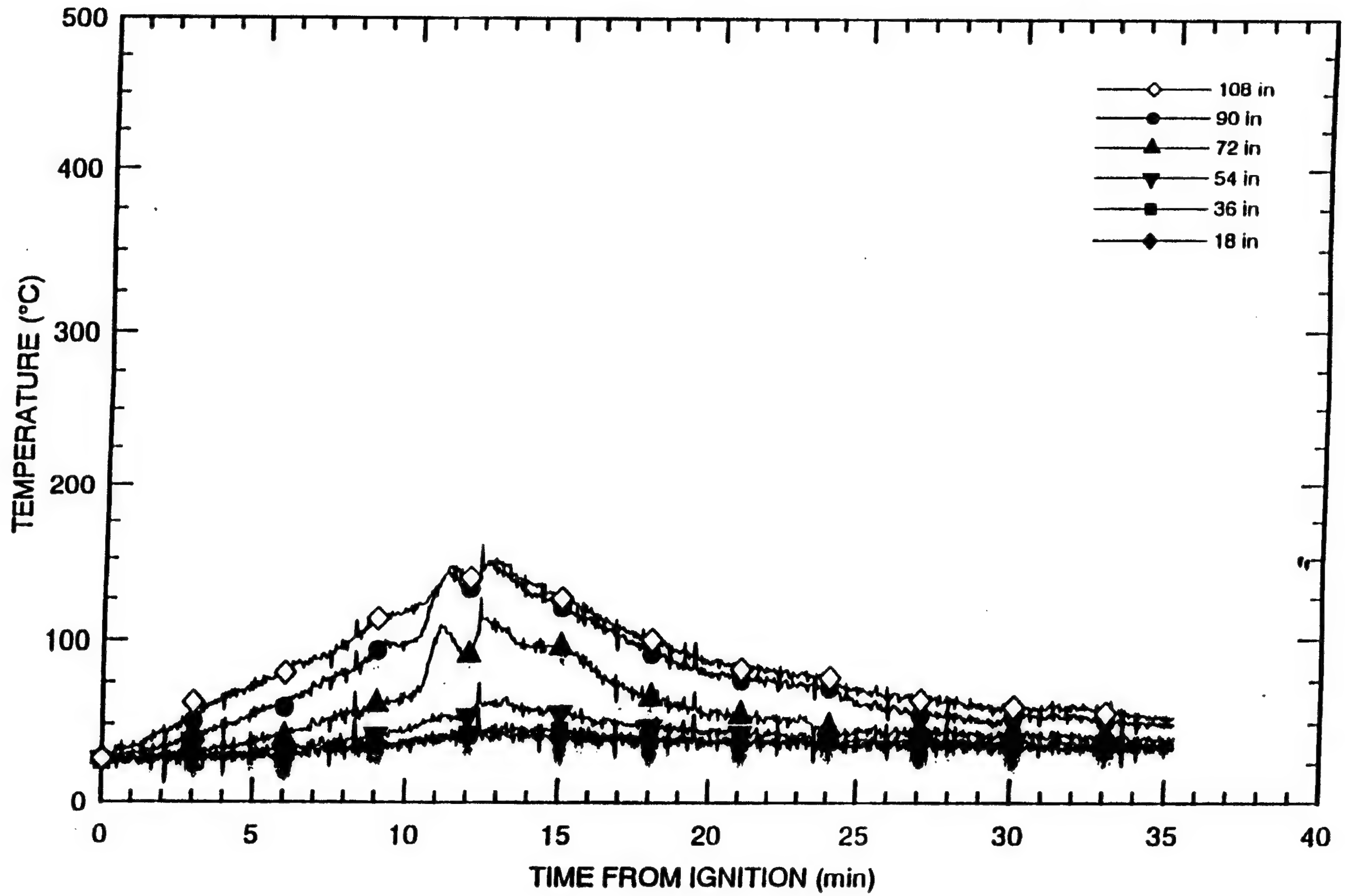


Fig. B149 - Starboard inner (2-21-1) thermocouple tree for FOG_18

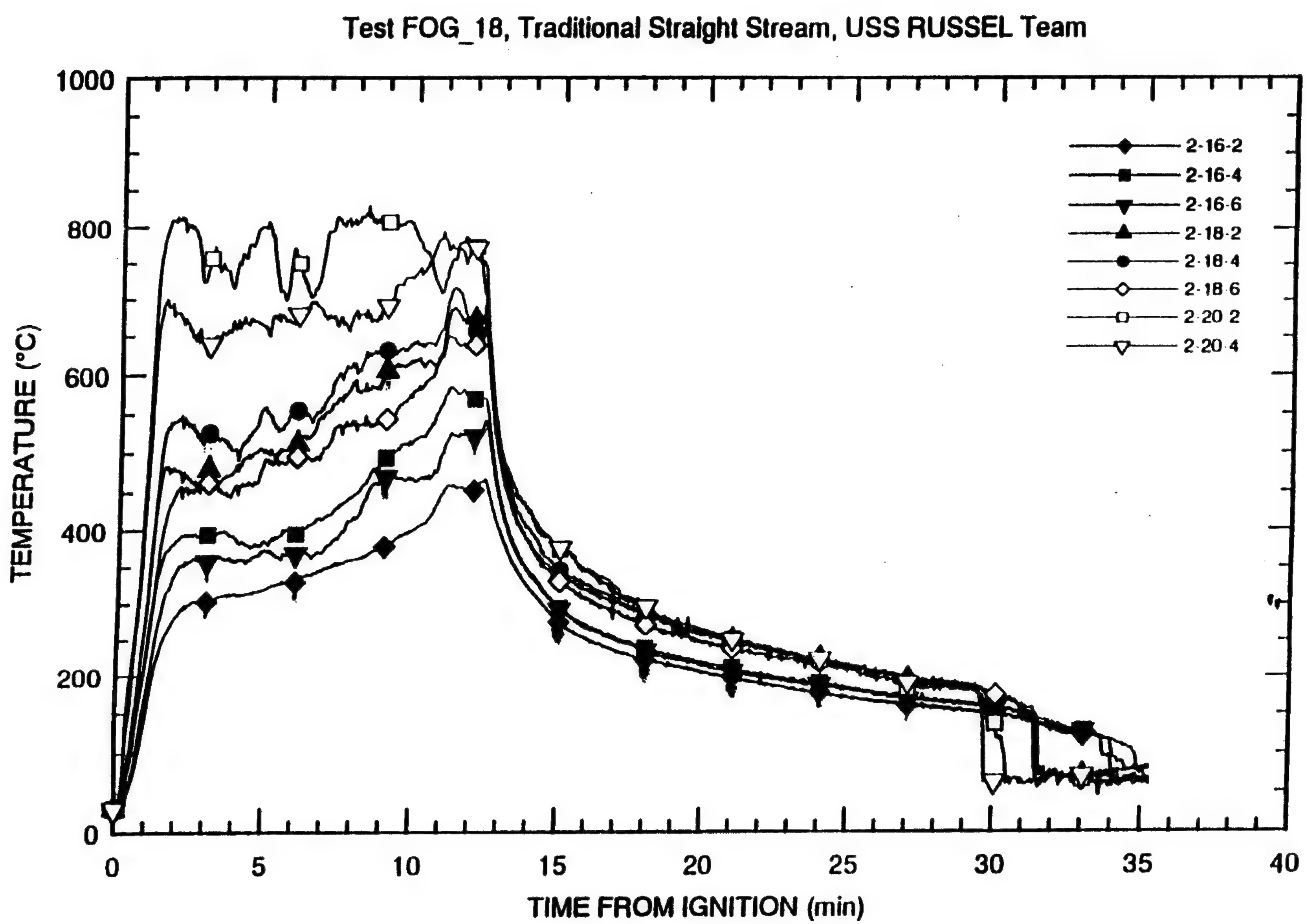


Fig. B150 - Burn room overhead temperatures for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

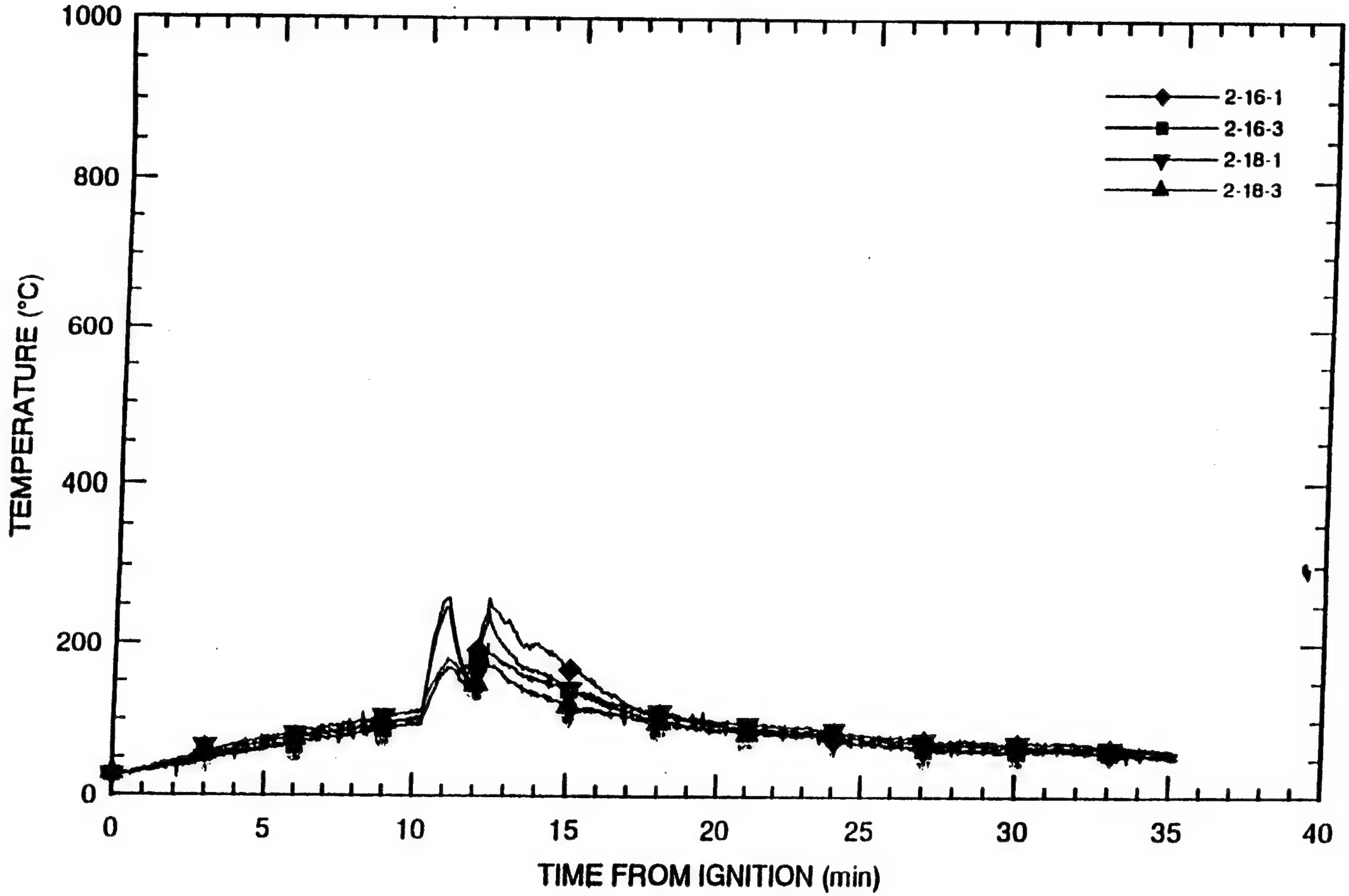


Fig. B151 - GSK overhead temperatures for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

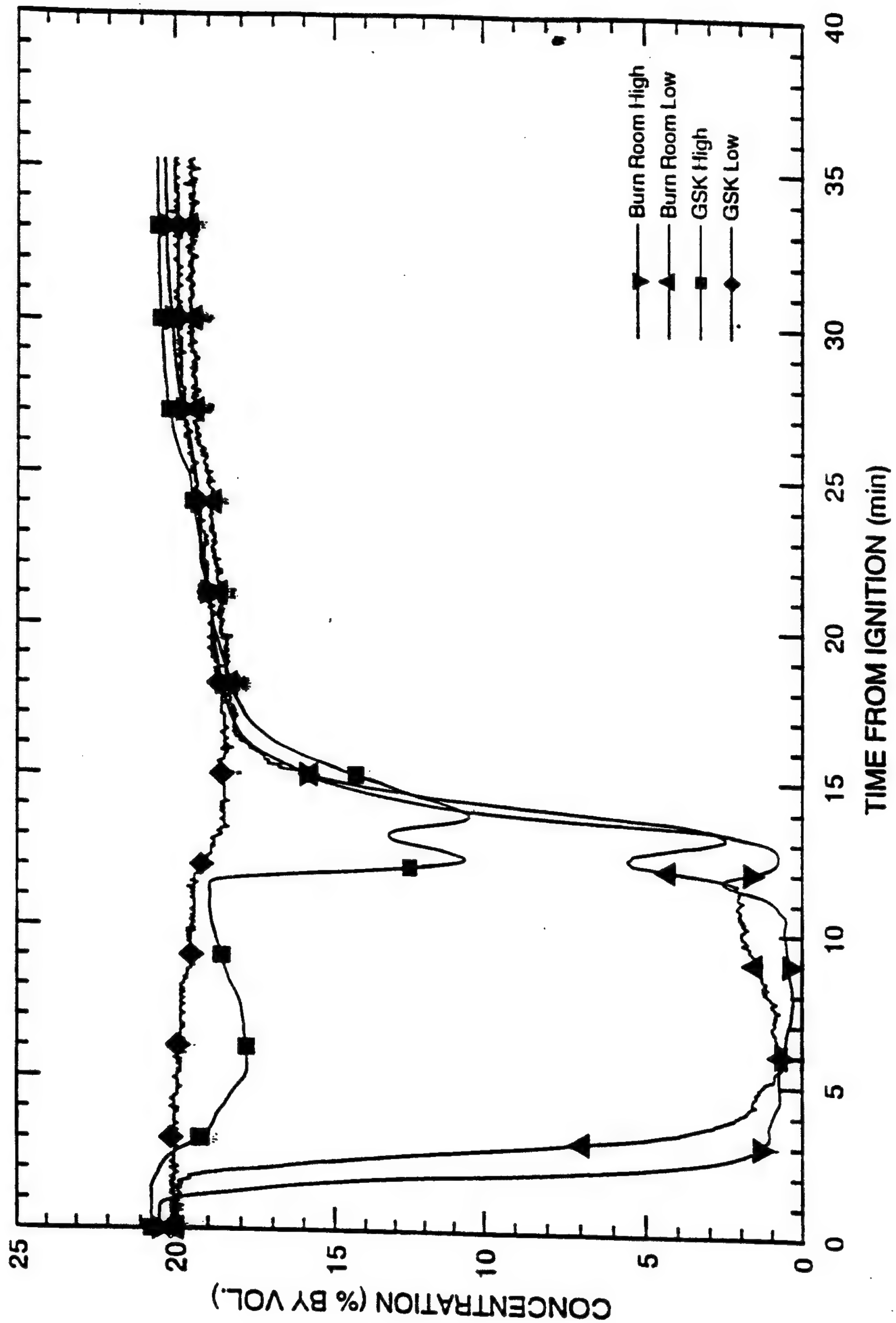


Fig. B152 - Oxygen (O_2) concentrations for FOG_18

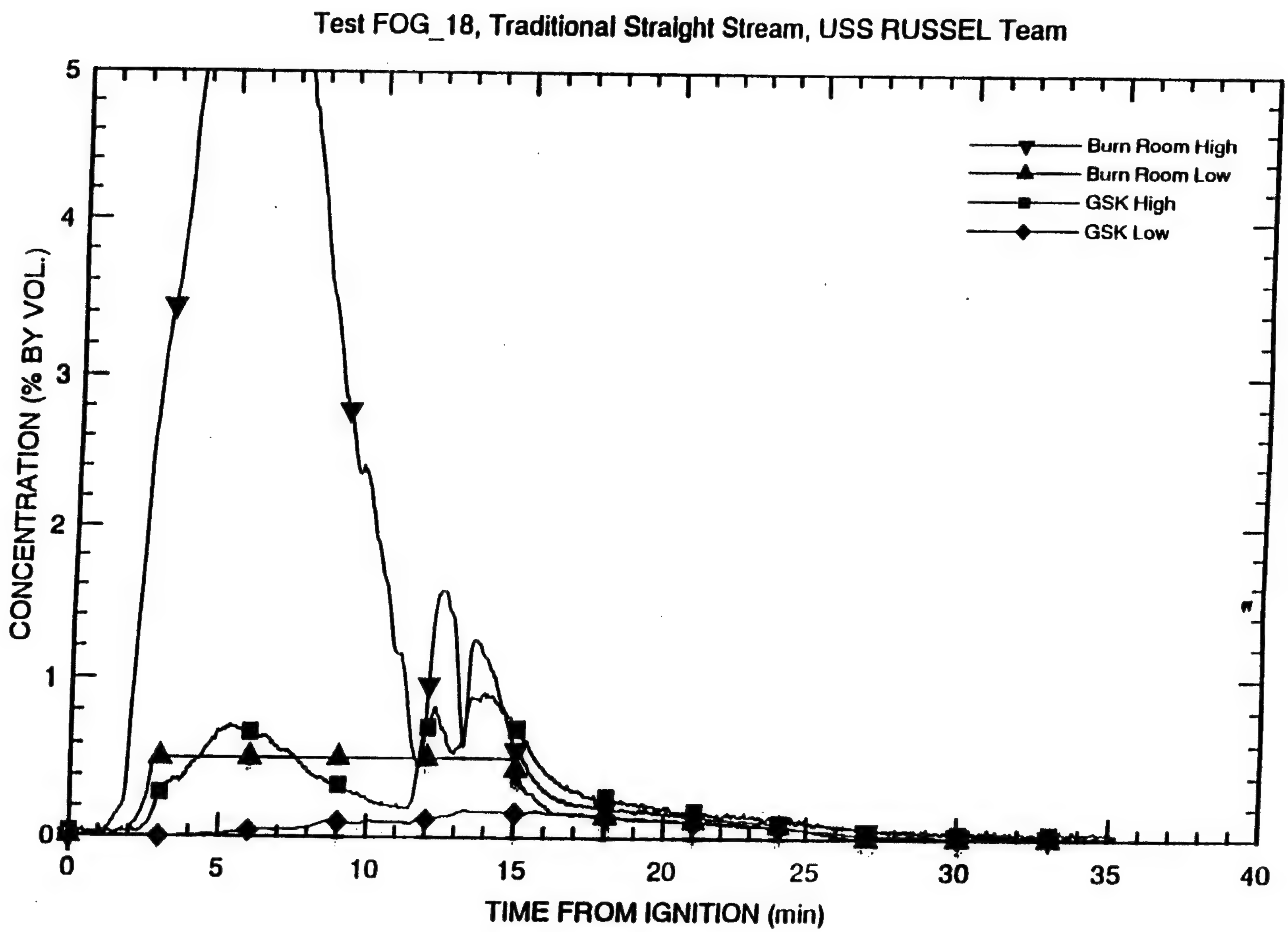


Fig. B153 - Carbon monoxide (CO) concentrations for FOG_18

Test FOG_18, Traditional Straight Stream, USS RUSSEL Team

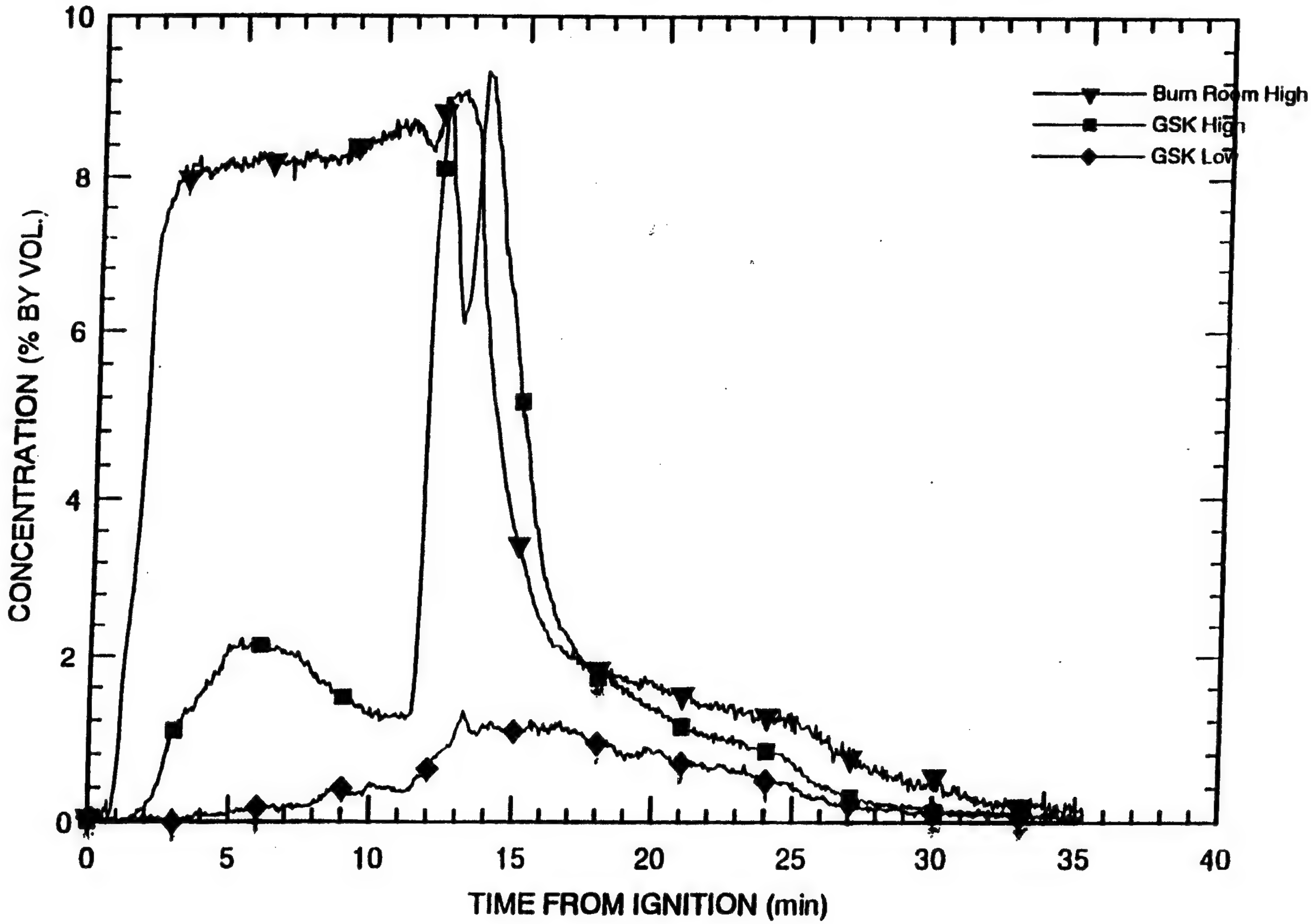


Fig. B154 - Carbon dioxide (CO_2) concentrations for FOG_18

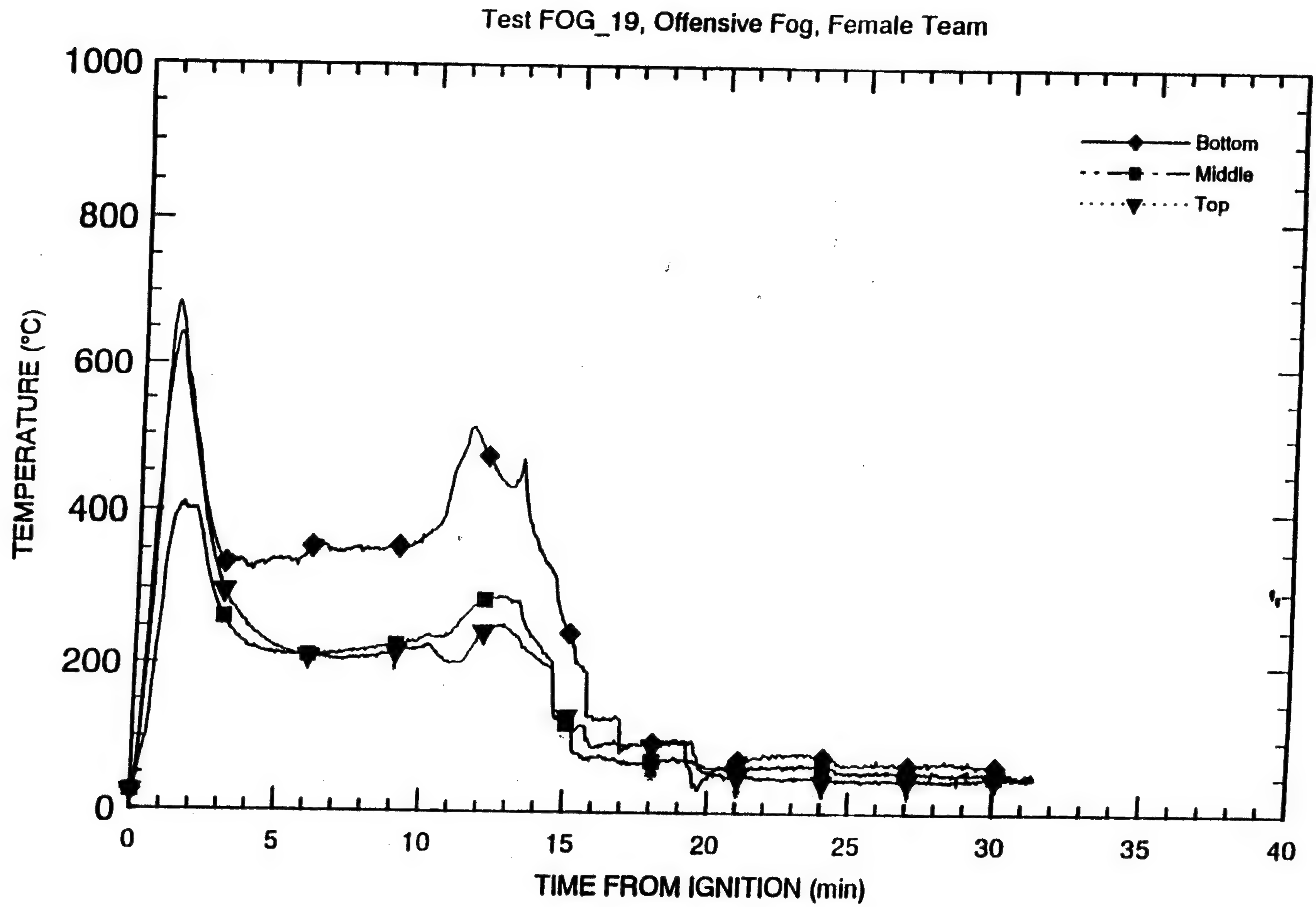


Fig. B155 - Wood crib #1 thermocouples for FOG_19

Test FOG_19, Offensive Fog, Female Team

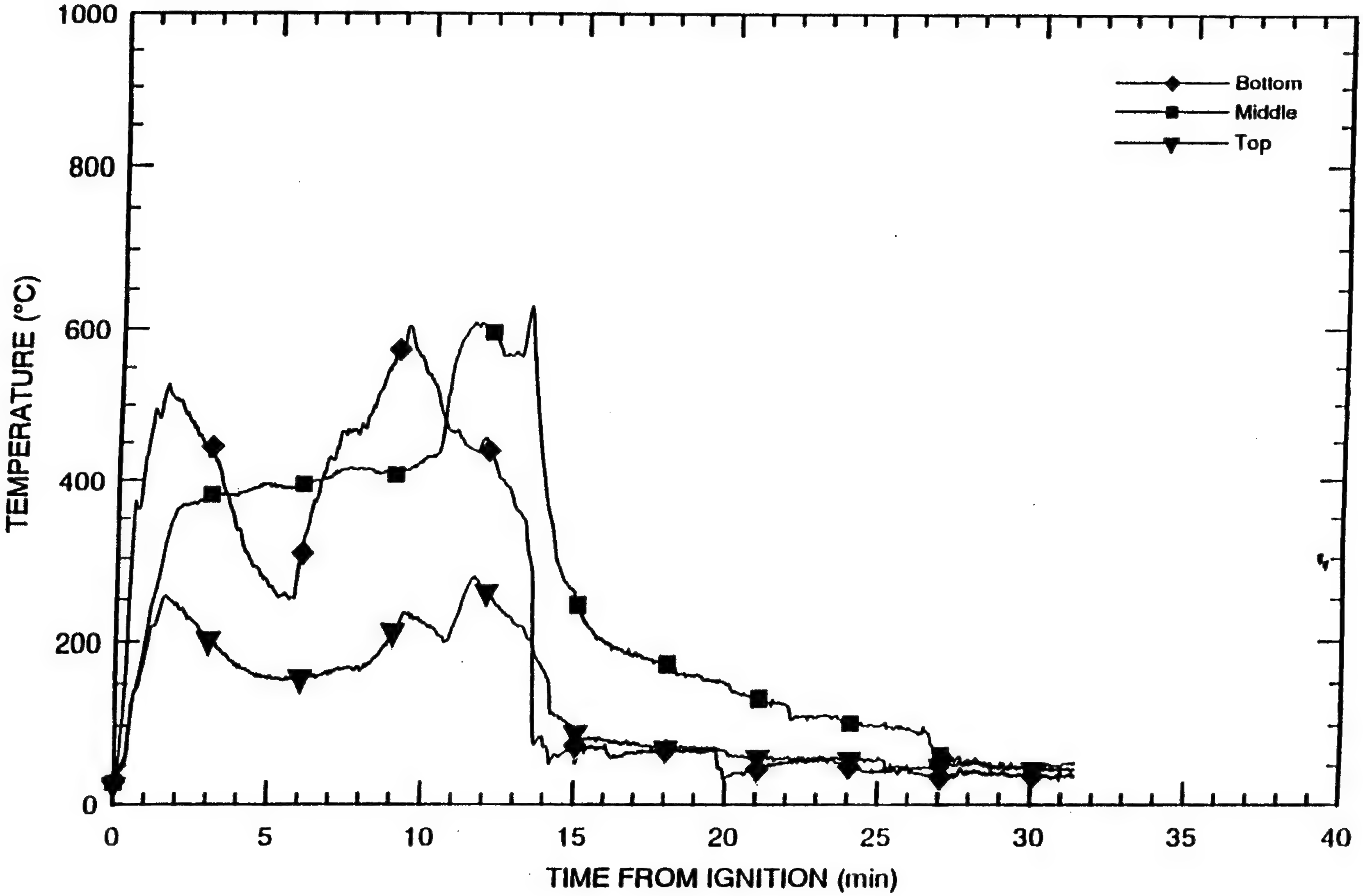


Fig. B156 - Wood crib #2 thermocouples for FOG_19

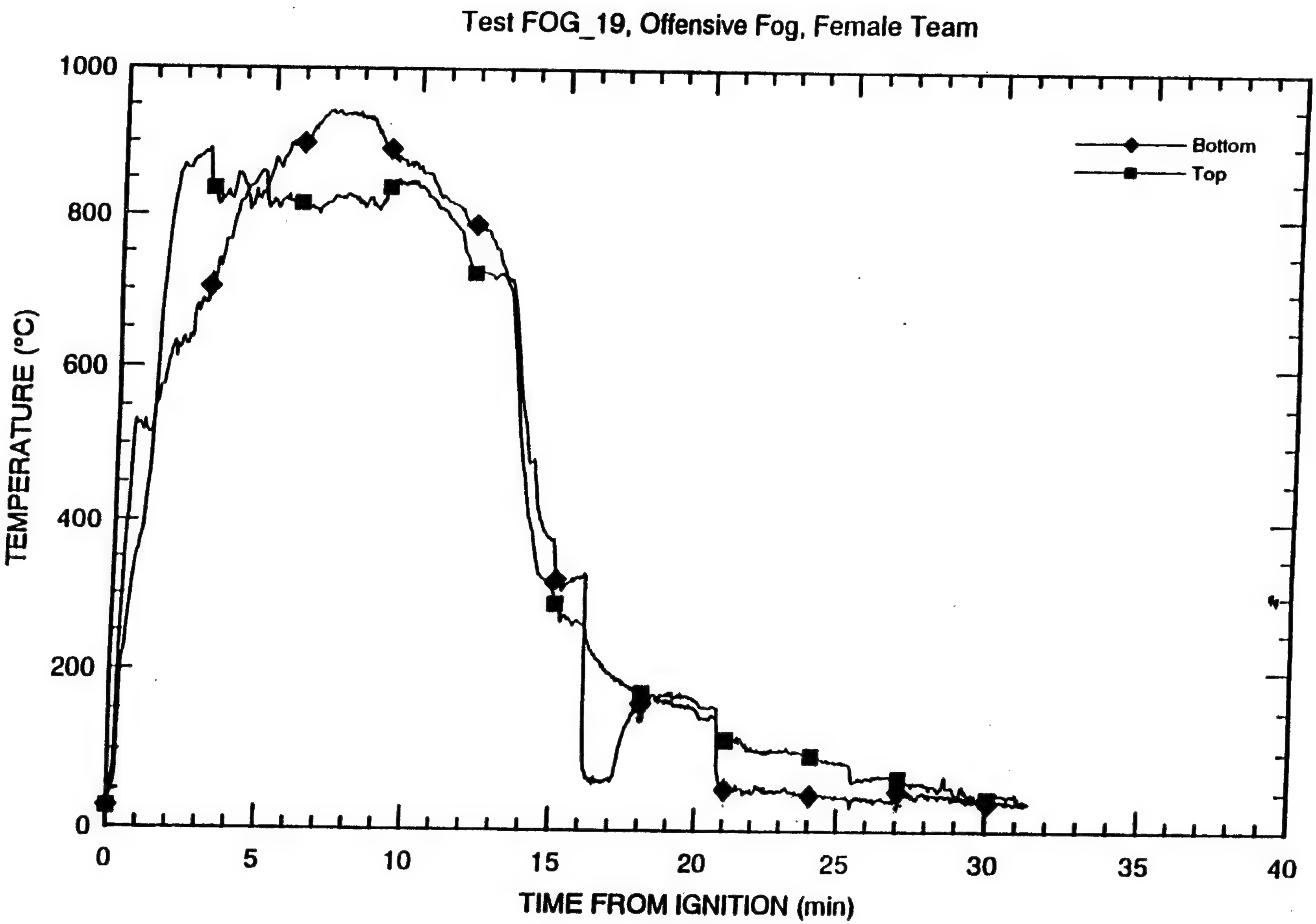


Fig. B157 - Wood crib #3 thermocouples for FOG_19

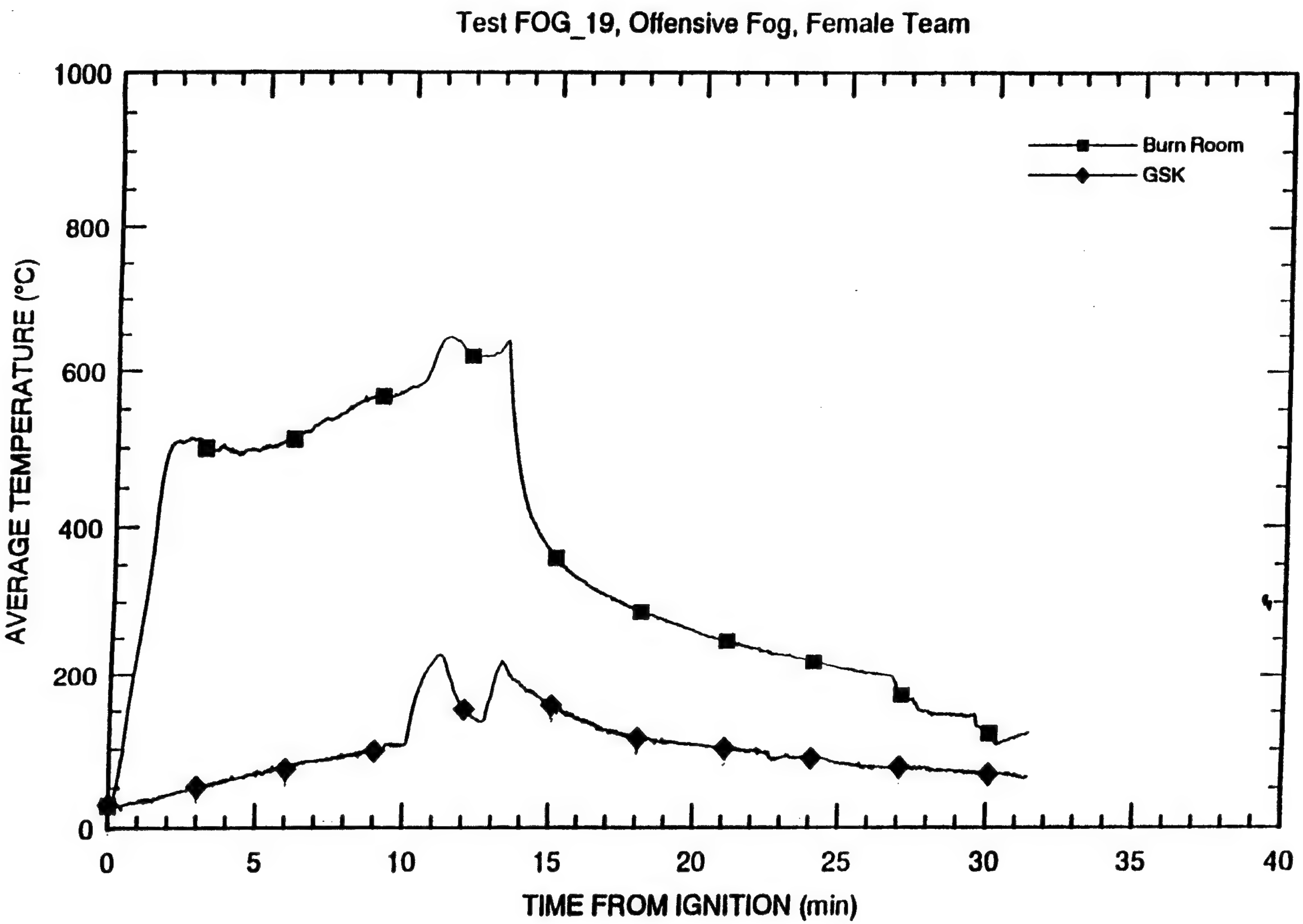


Fig. B158 - Average of overhead thermocouples for FOG_19

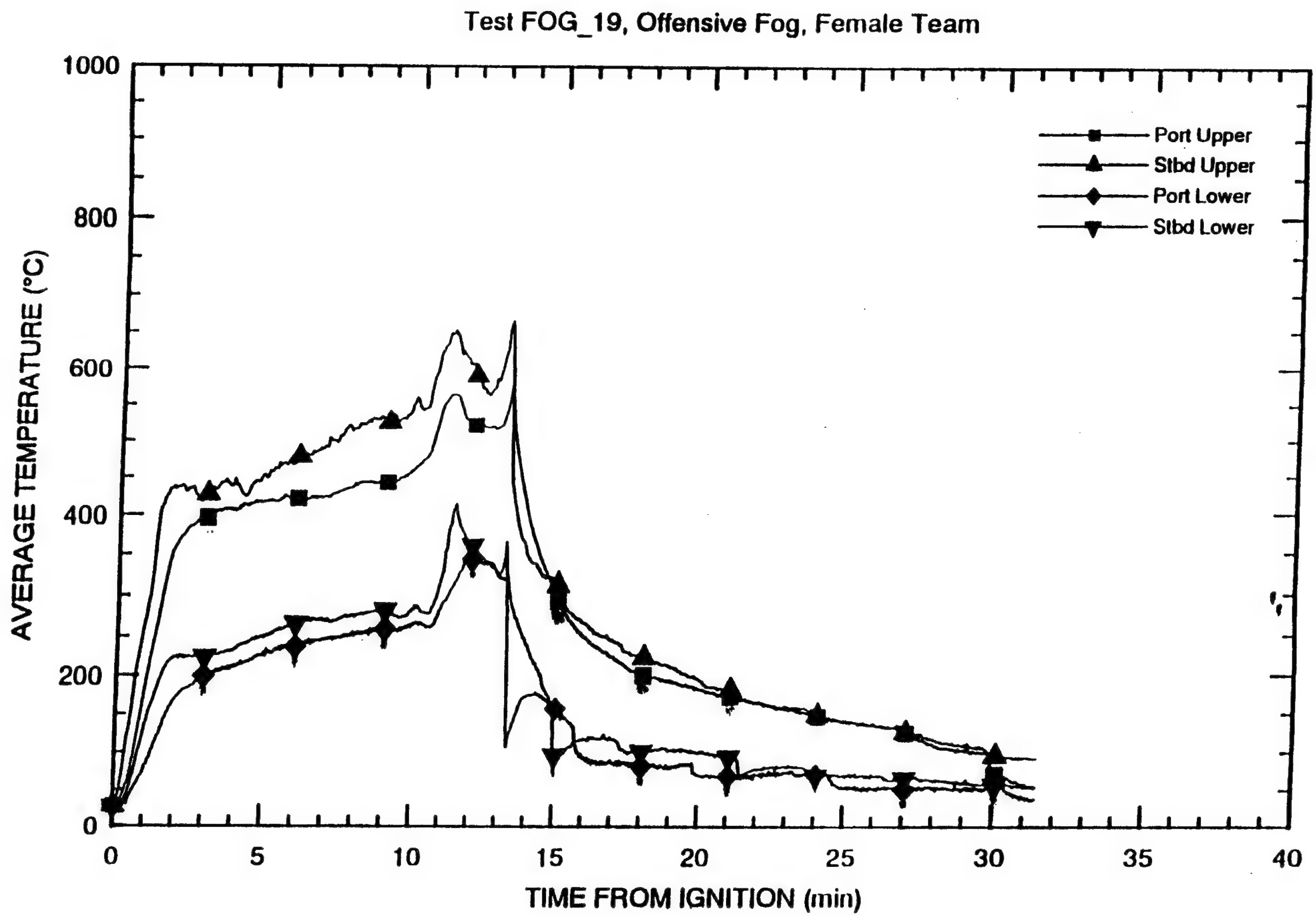


Fig. B159 - Burn room thermocouple string averages (upper vs. lower) for FOG_19

Test FOG_19, Offensive Fog, Female Team

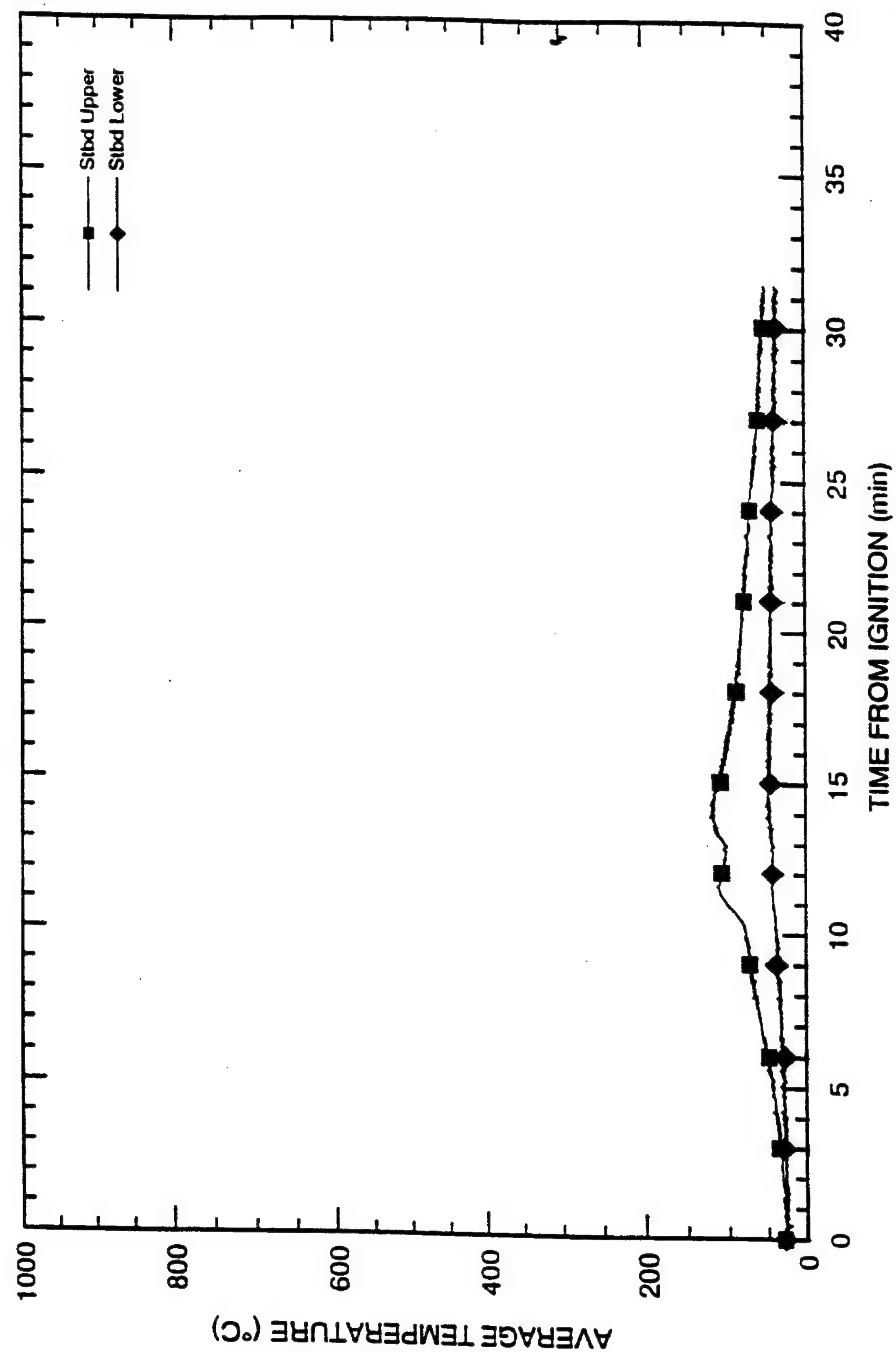


Fig. B160 - GSK thermocouple string averages (upper vs. lower) for FOG_19

Test FOG_19, Offensive Fog, Female Team

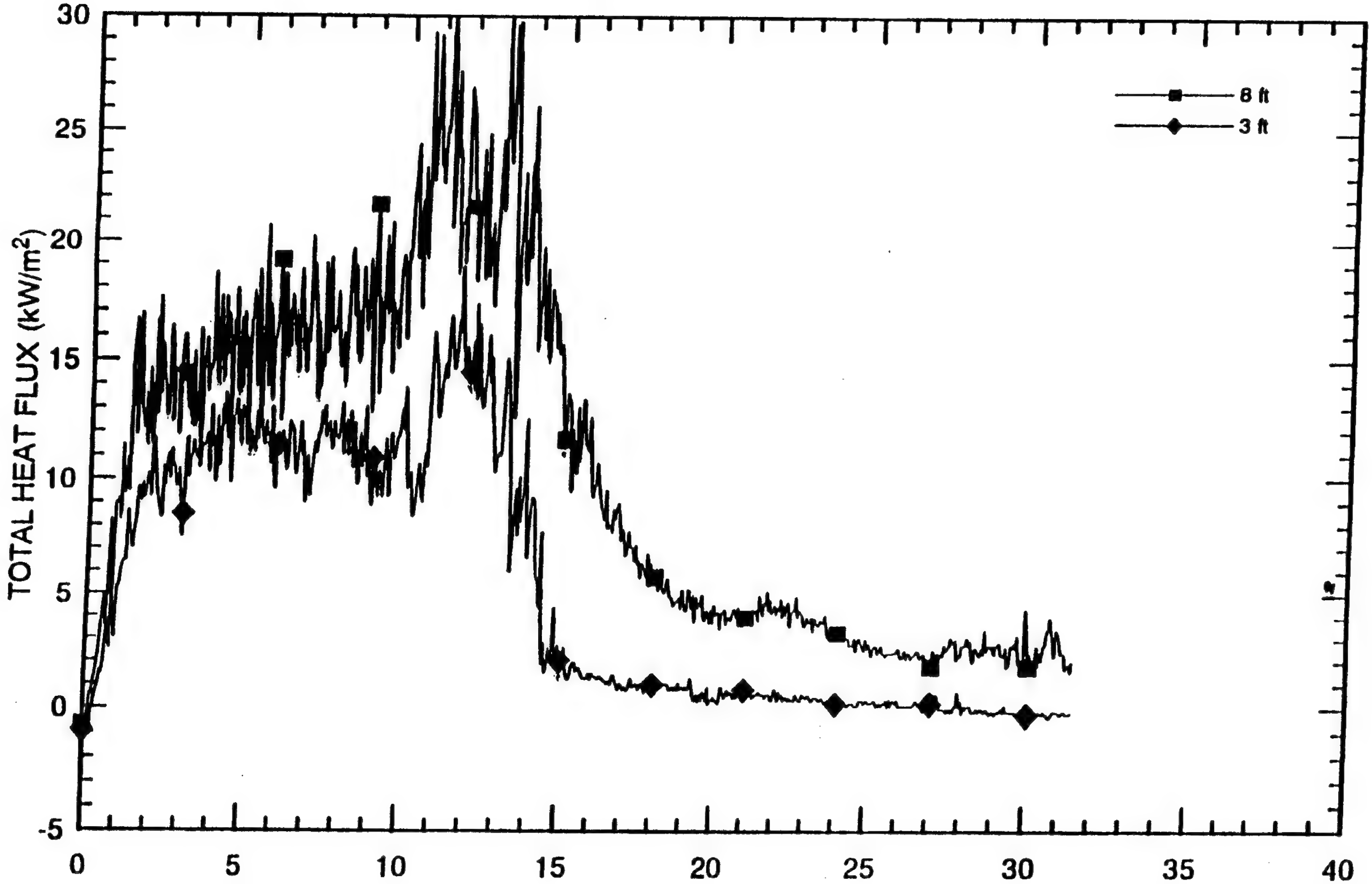


Fig. B161 - Burn room calorimeters for FOG_19

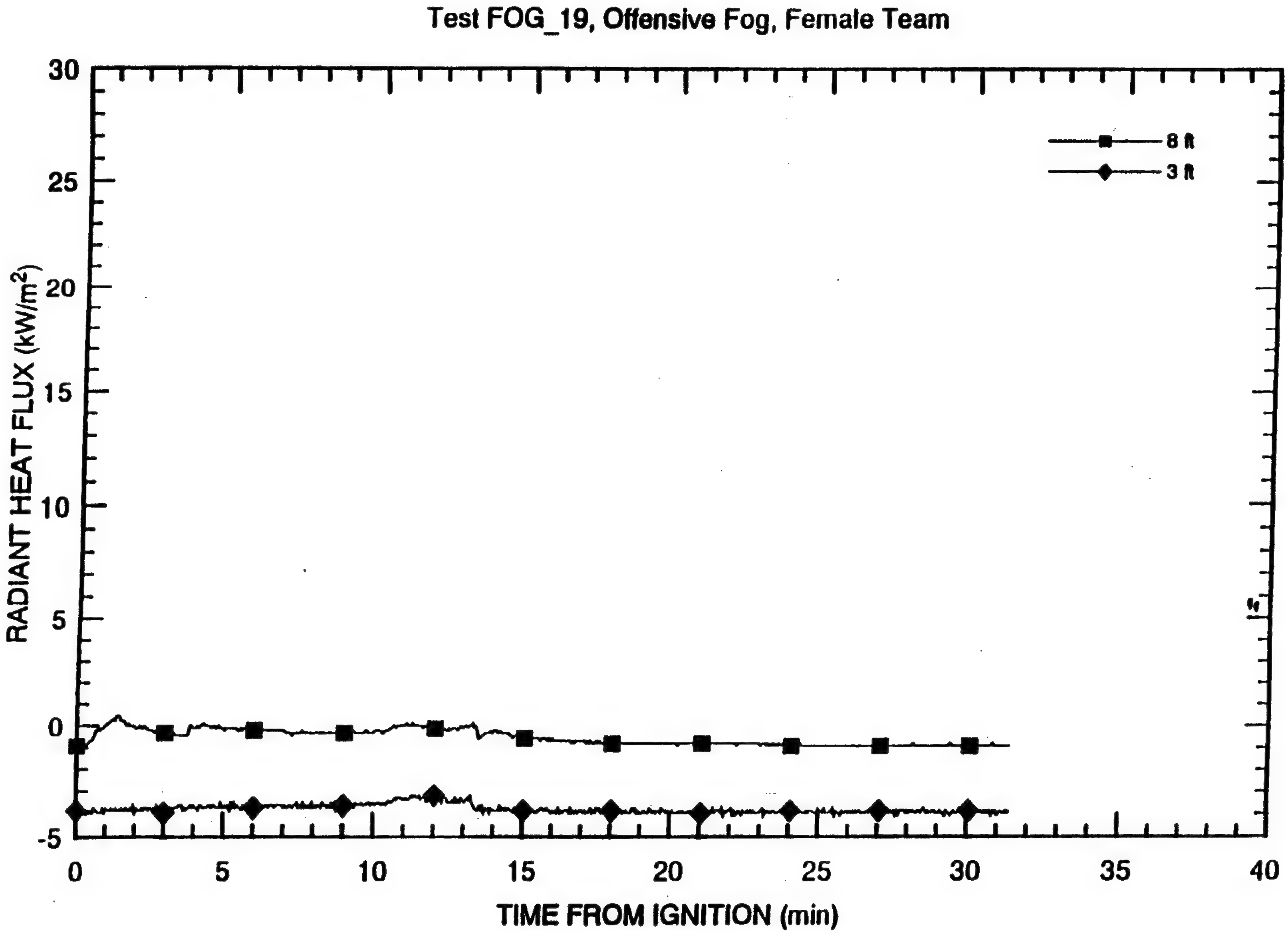


Fig. B162 - Burn room radiometers for FOG_19

Test FOG_19, Offensive Fog, Female Team

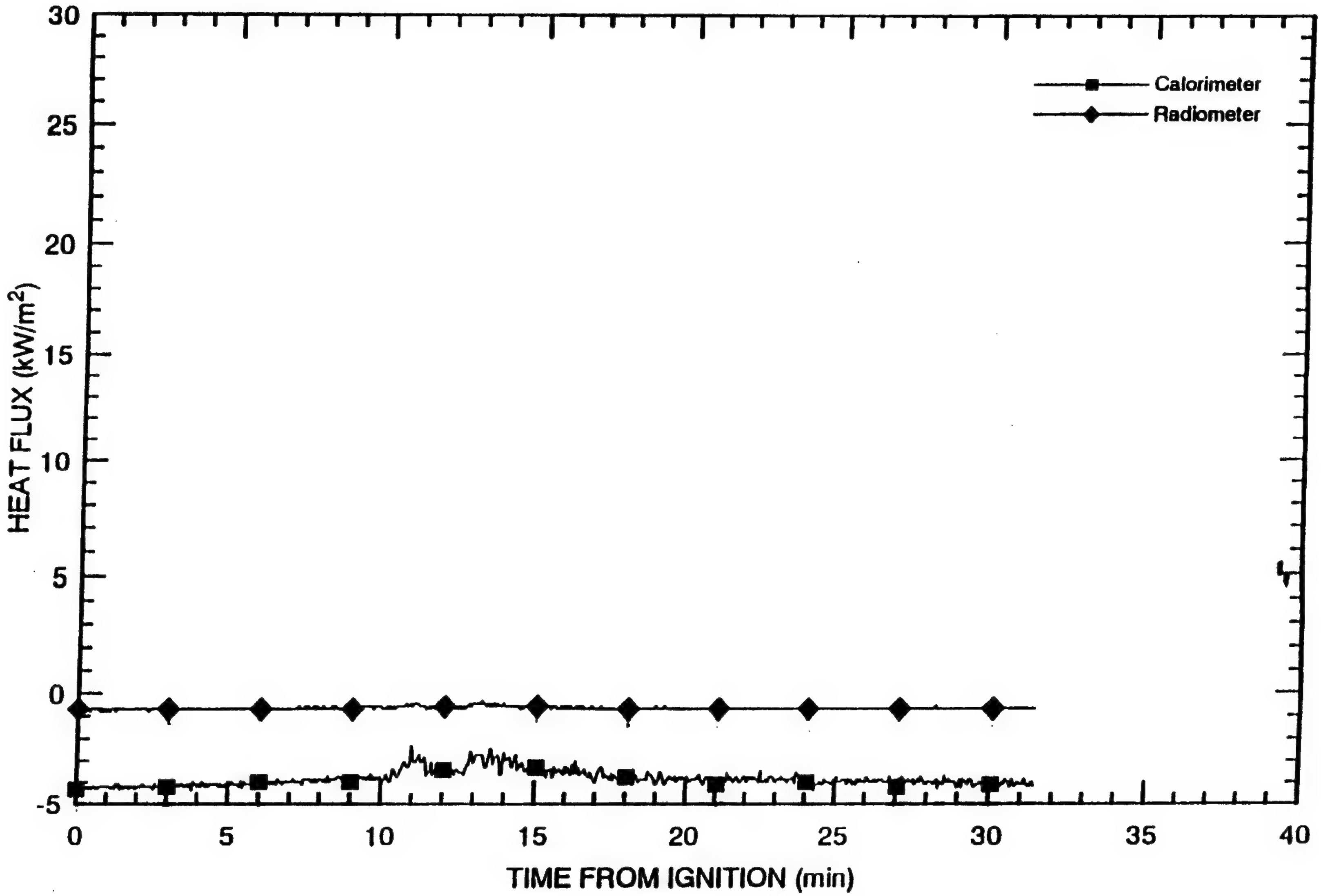


Fig. B163 - GSK radiometer and calorimeter for FOG_19

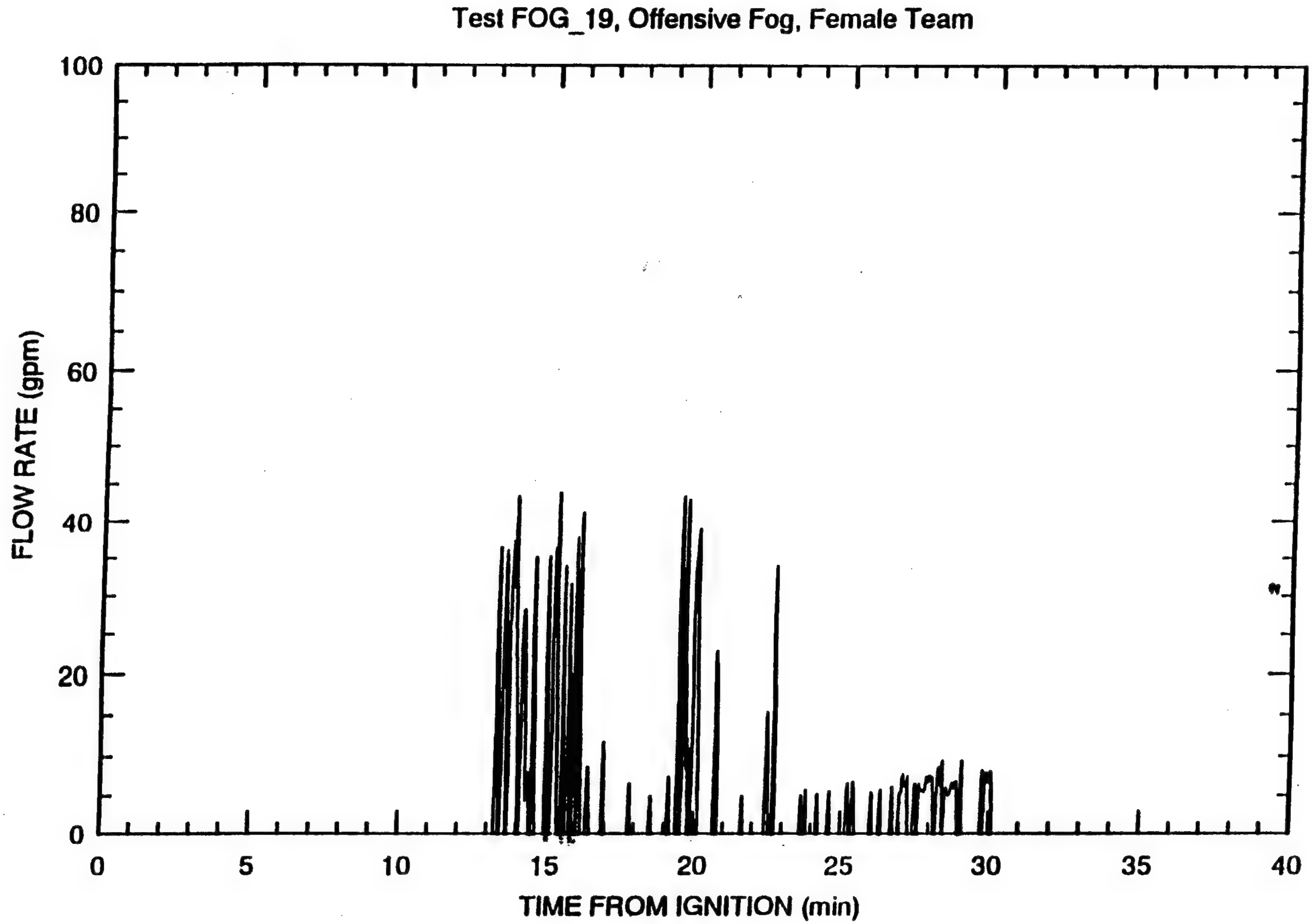


Fig. B164 - Water flow rate for FOG_19

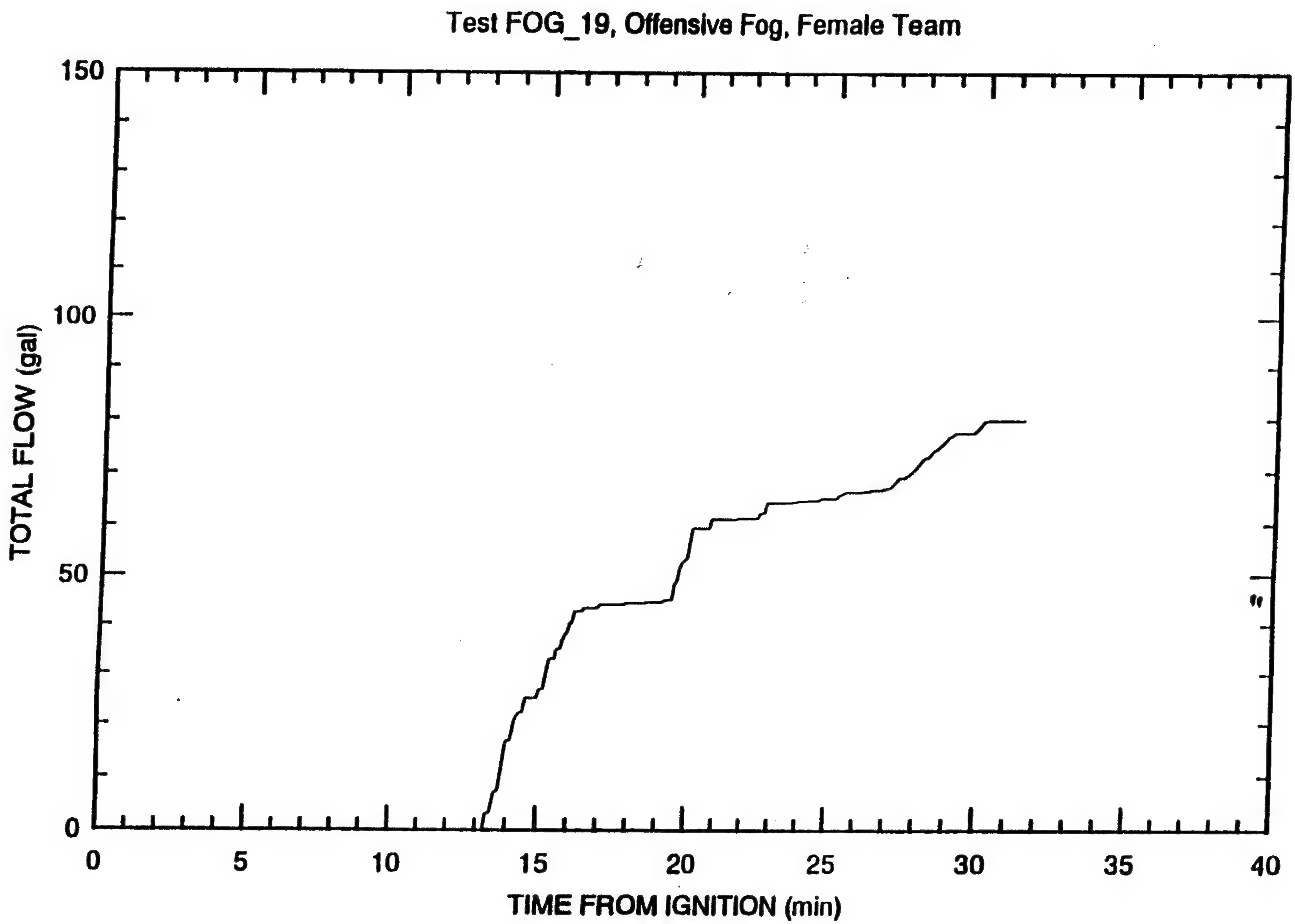


Fig. B165 - Cumulative water flow for FOG_19

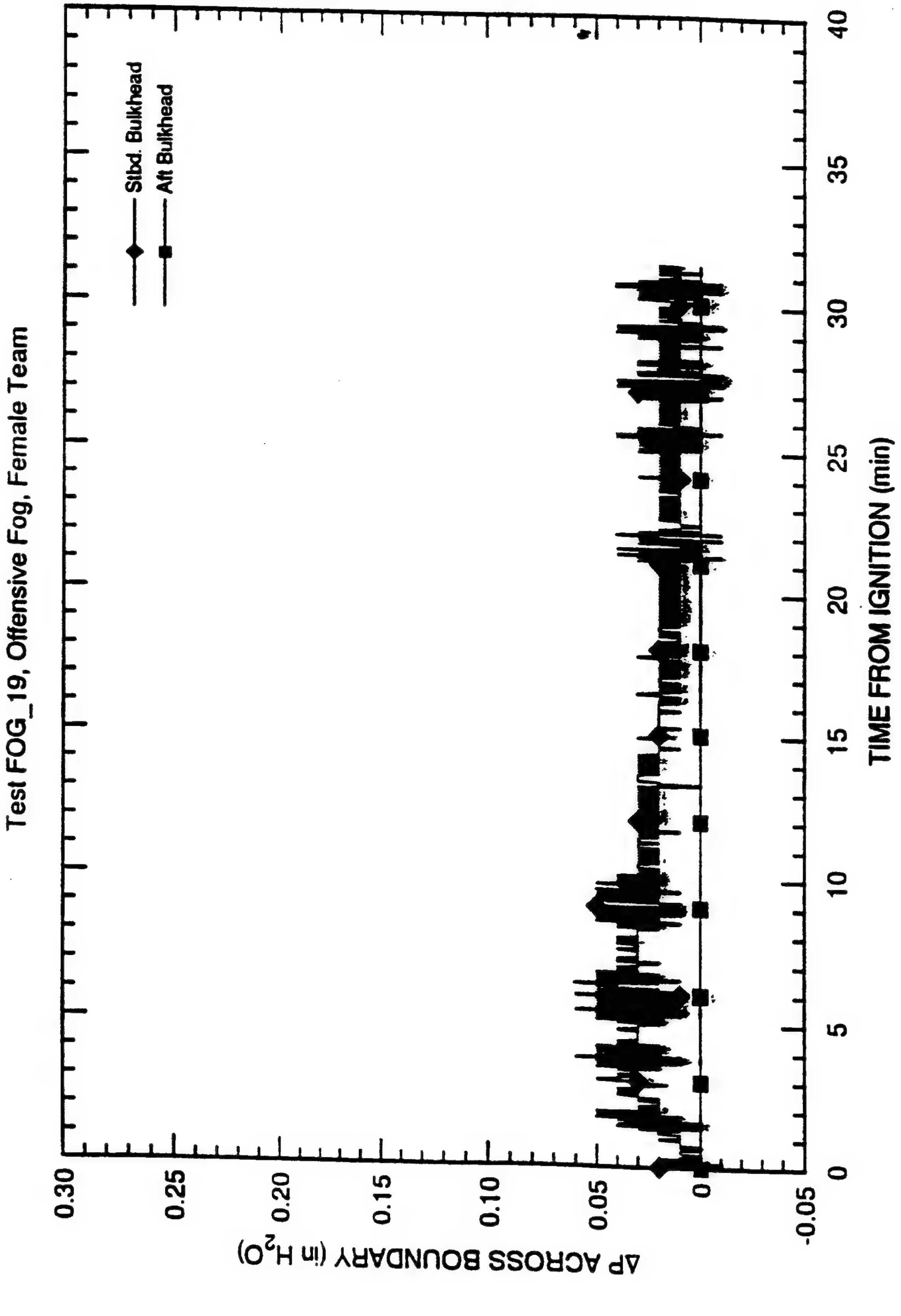


Fig. B166 - Pressure differential across burn room boundaries for FOG_19

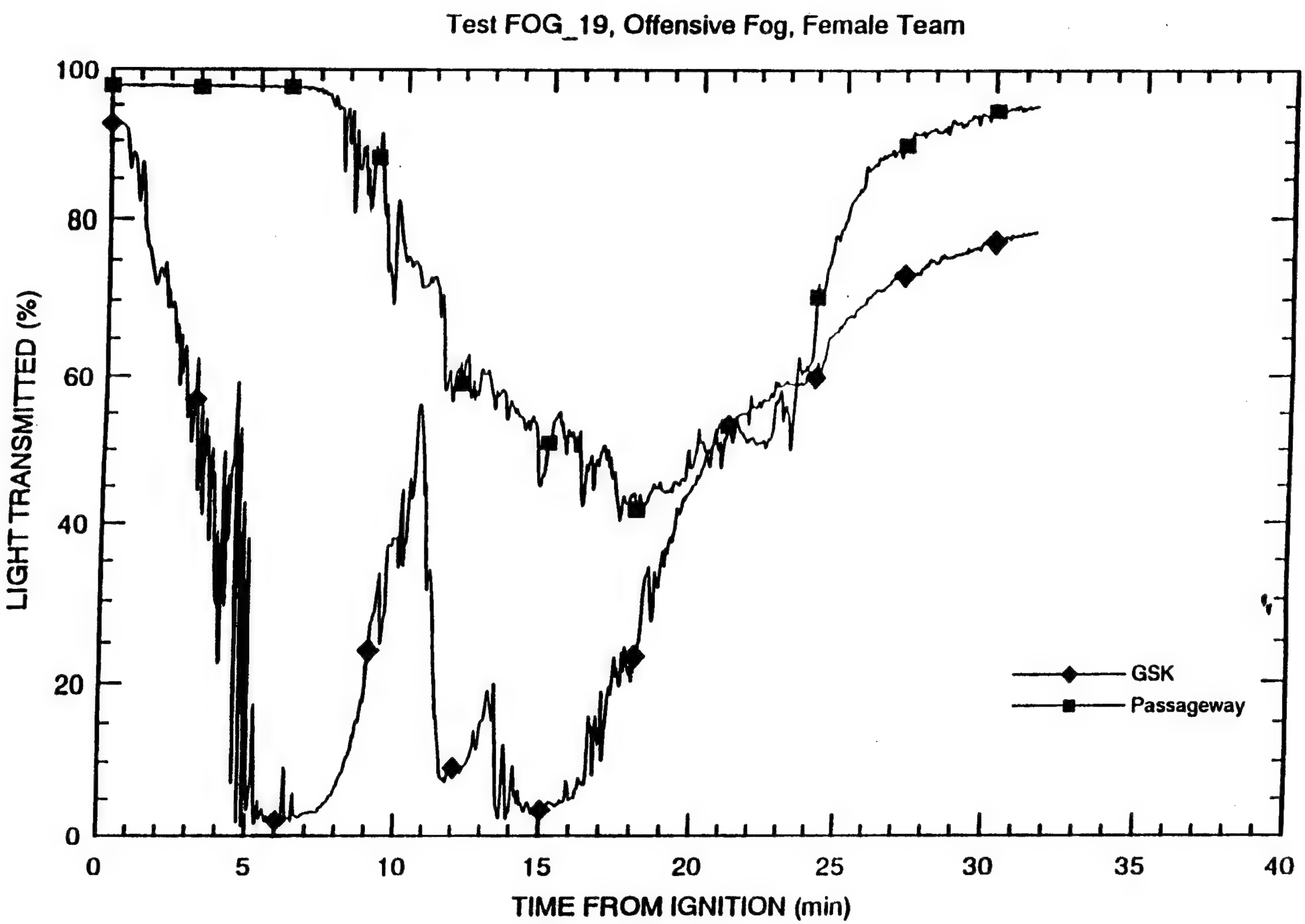


Fig. B167 - Smoke Obscuration for FOG_19

Test FOG_19, Offensive Fog, Female Team

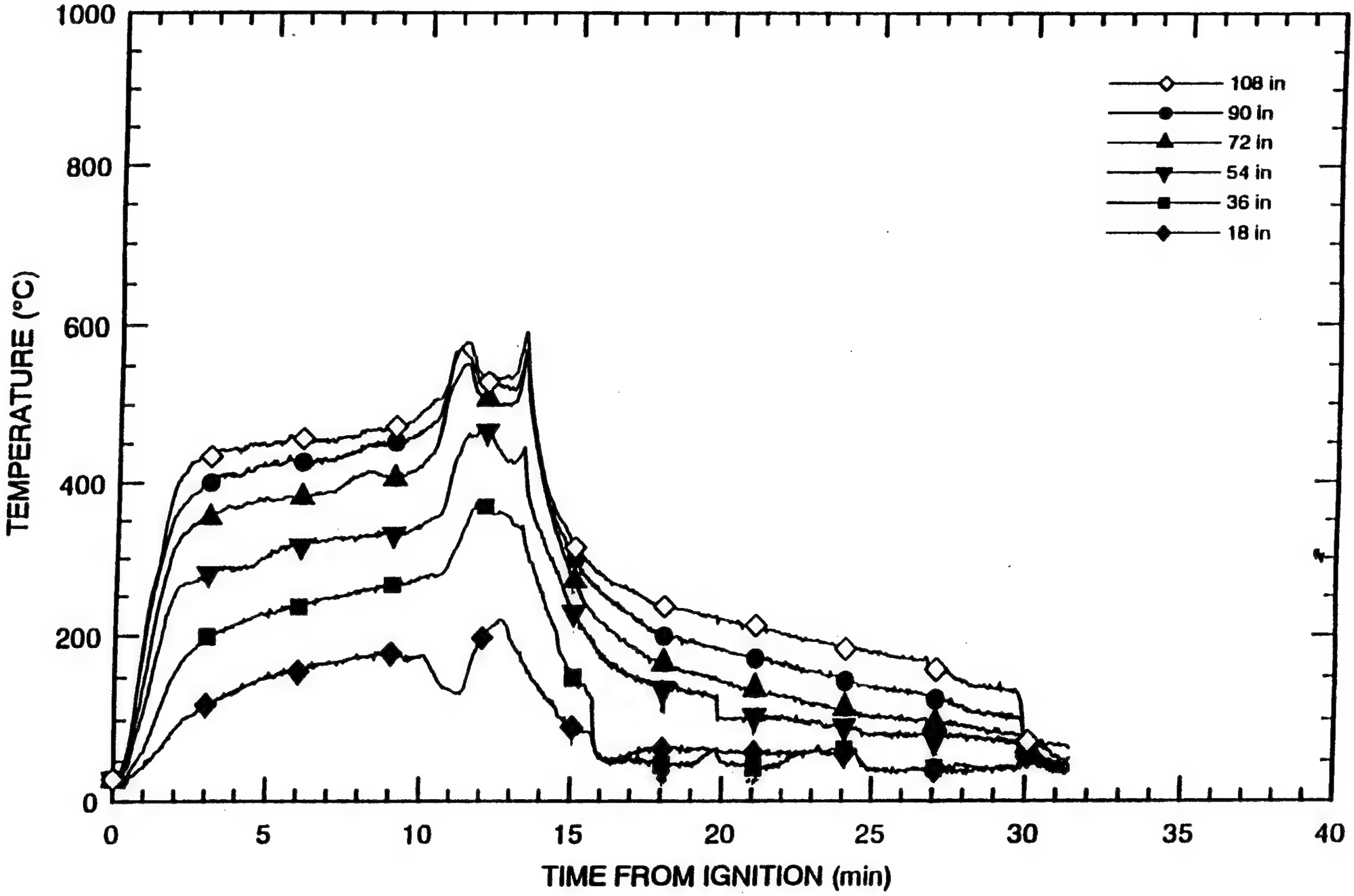


Fig. B168 - Port outer (2-18-2) thermocouple tree for FOG_19

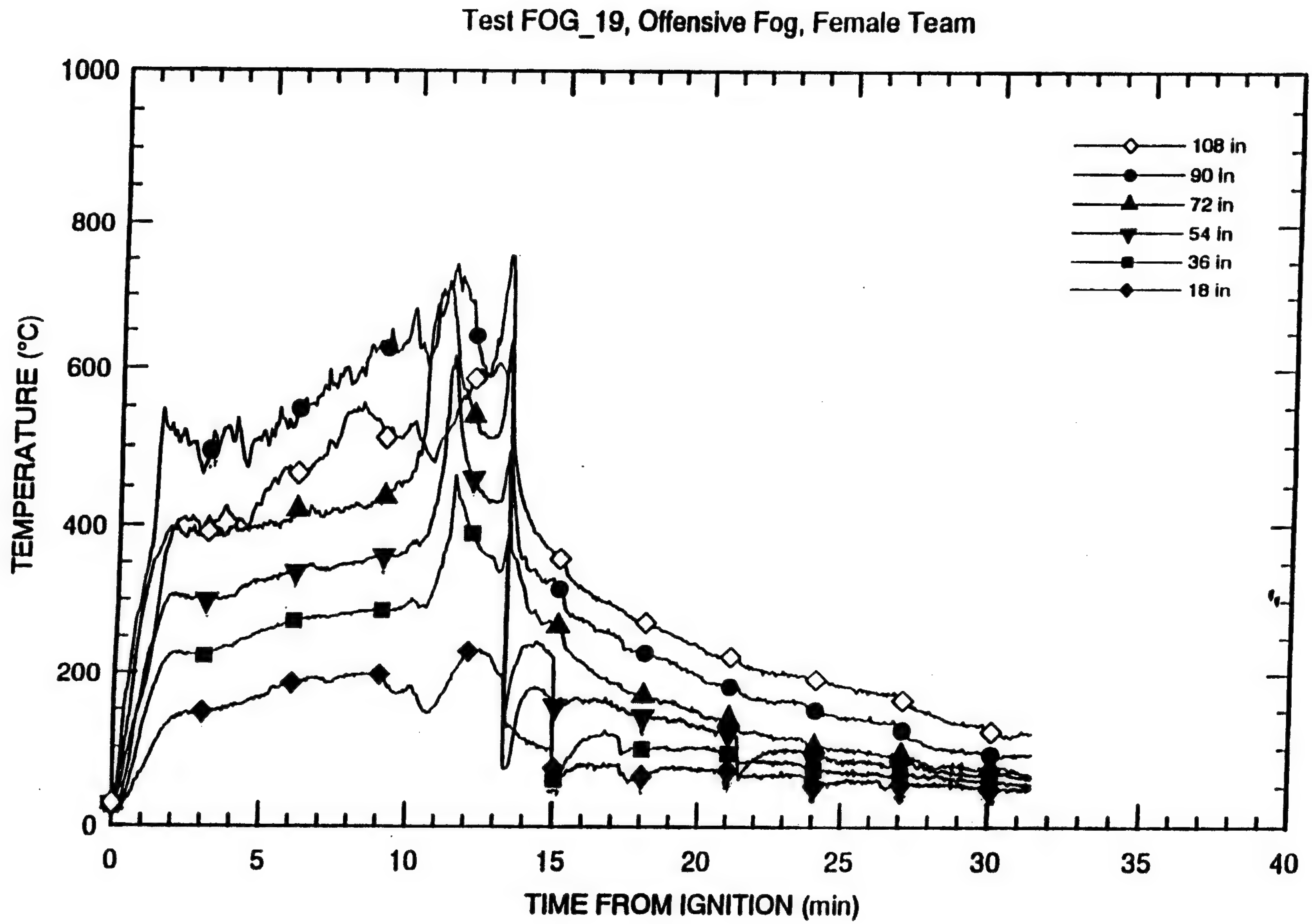


Fig. B169 - Port inner (2-19-0) thermocouple tree for FOG_19

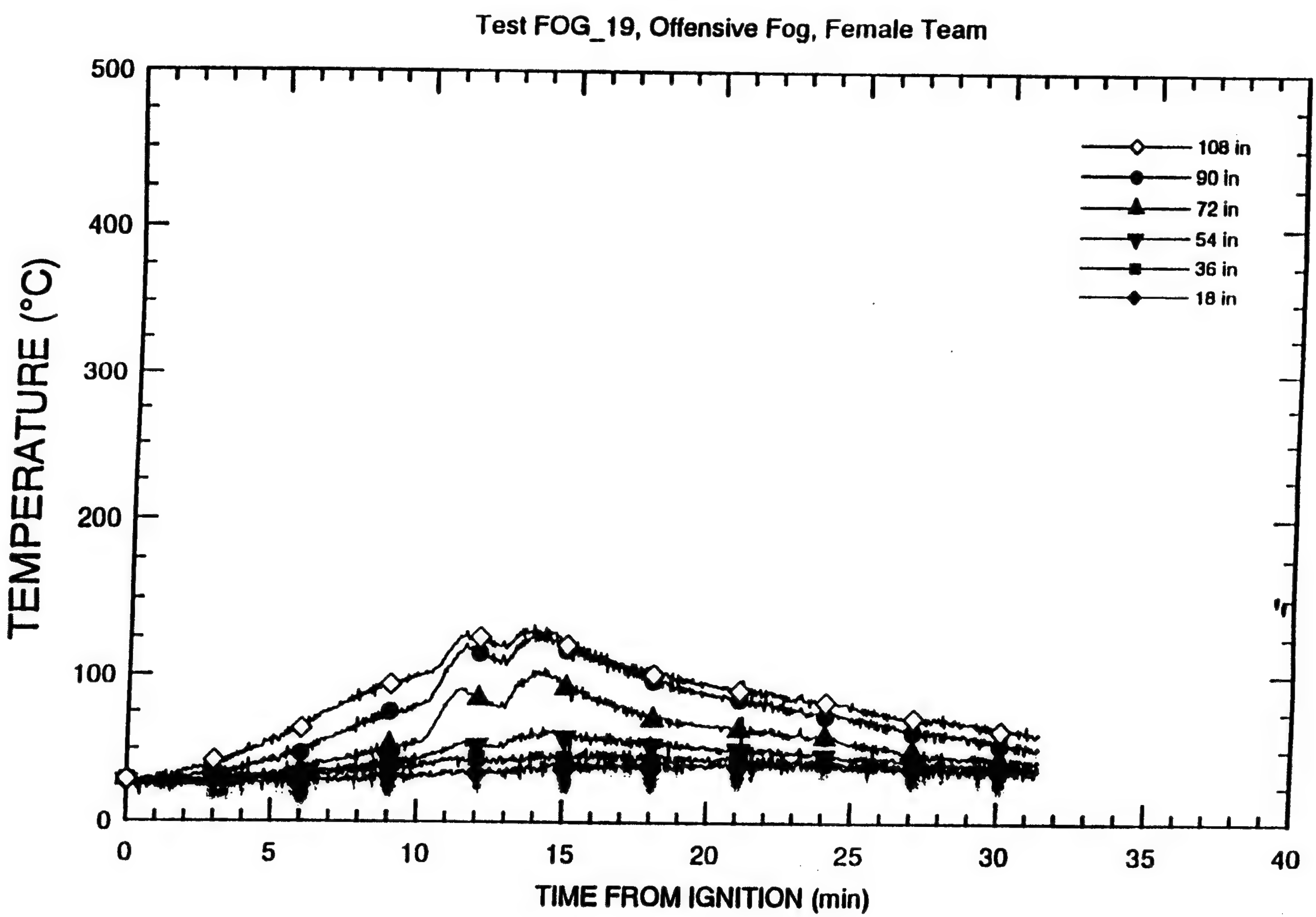


Fig. B170 - Starboard outer (2-21-3) thermocouple tree for FOG_19

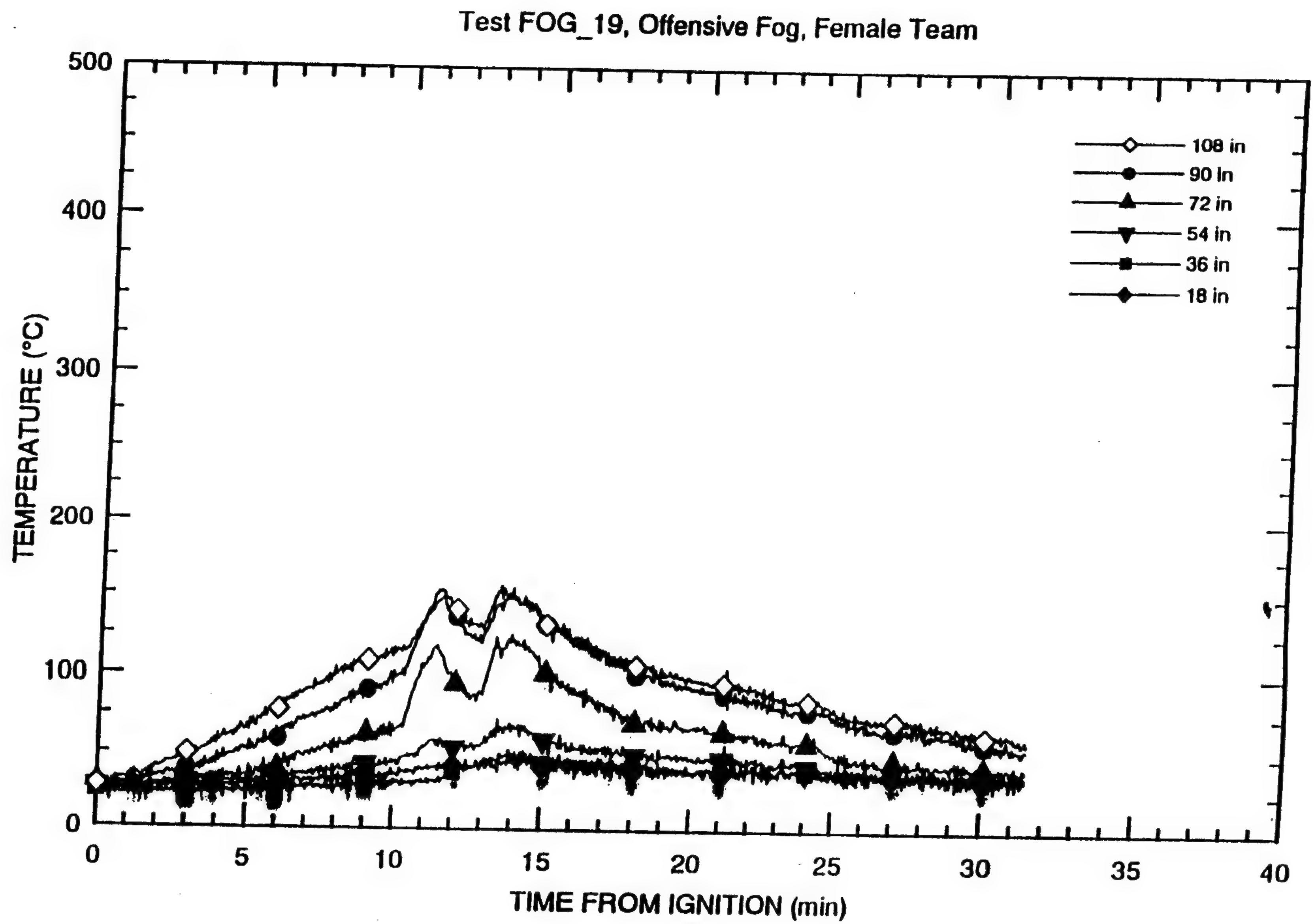


Fig. B171 - Starboard inner (2-21-1) thermocouple tree for FOG_19

Test FOG_19, Offensive Fog, Female Team

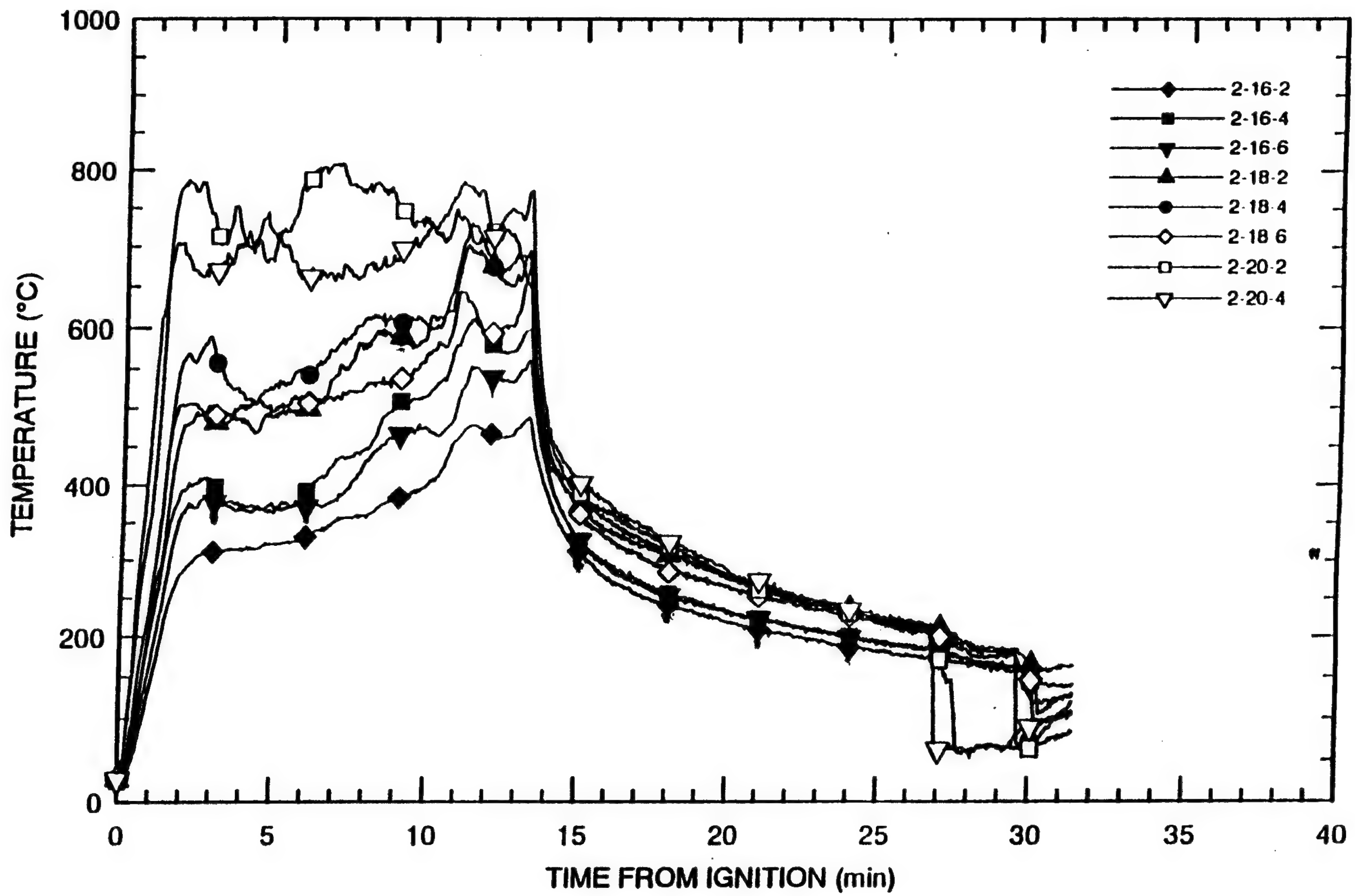


Fig. B172 - Burn room overhead temperatures for FOG_19

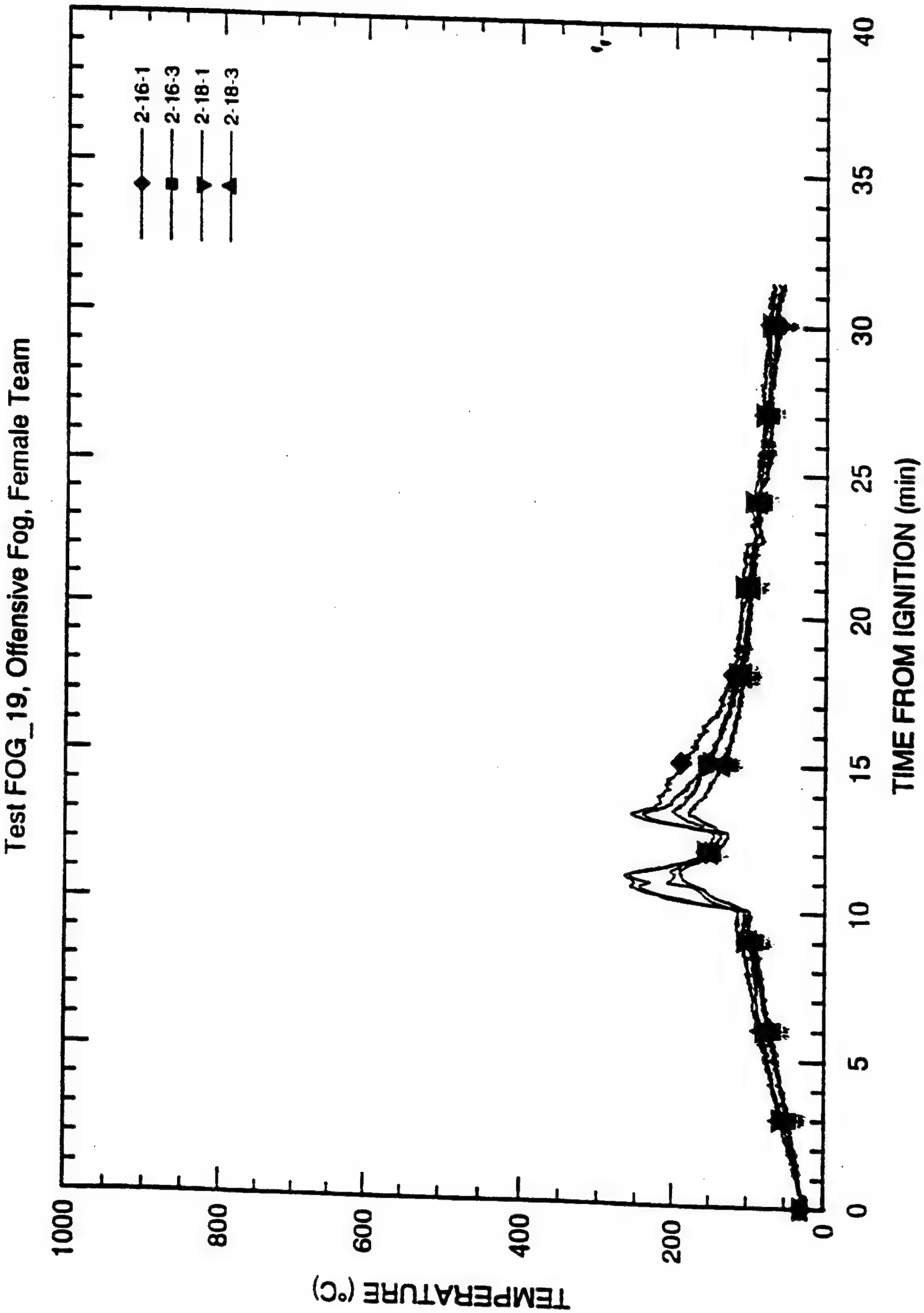


Fig. B173 - GSK overhead temperatures for FOG_19

Test FOG_19, Offensive Fog, Female Team

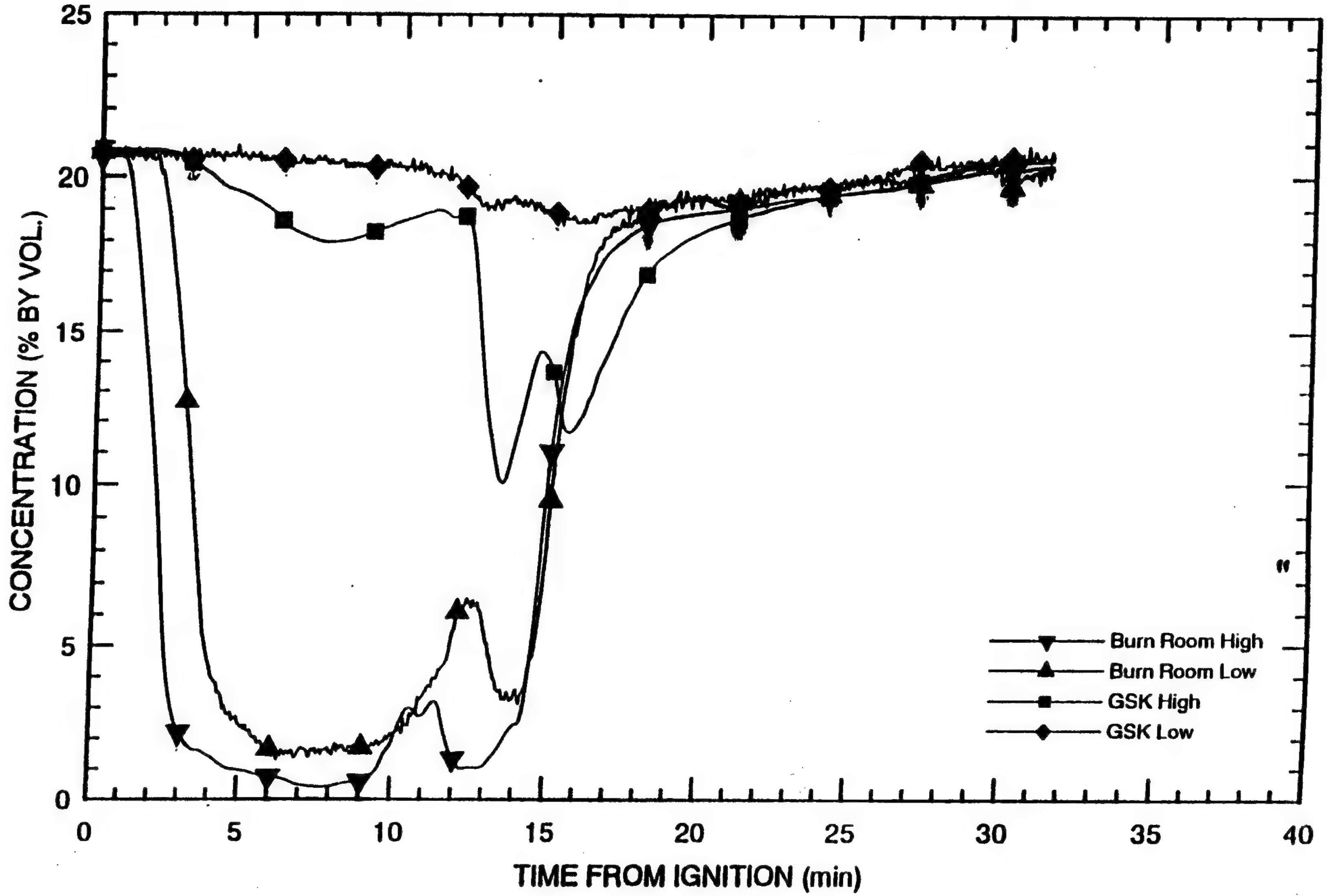


Fig. B174 - Oxygen (O_2) concentrations for FOG_19

Test FOG_19, Offensive Fog, Female Team

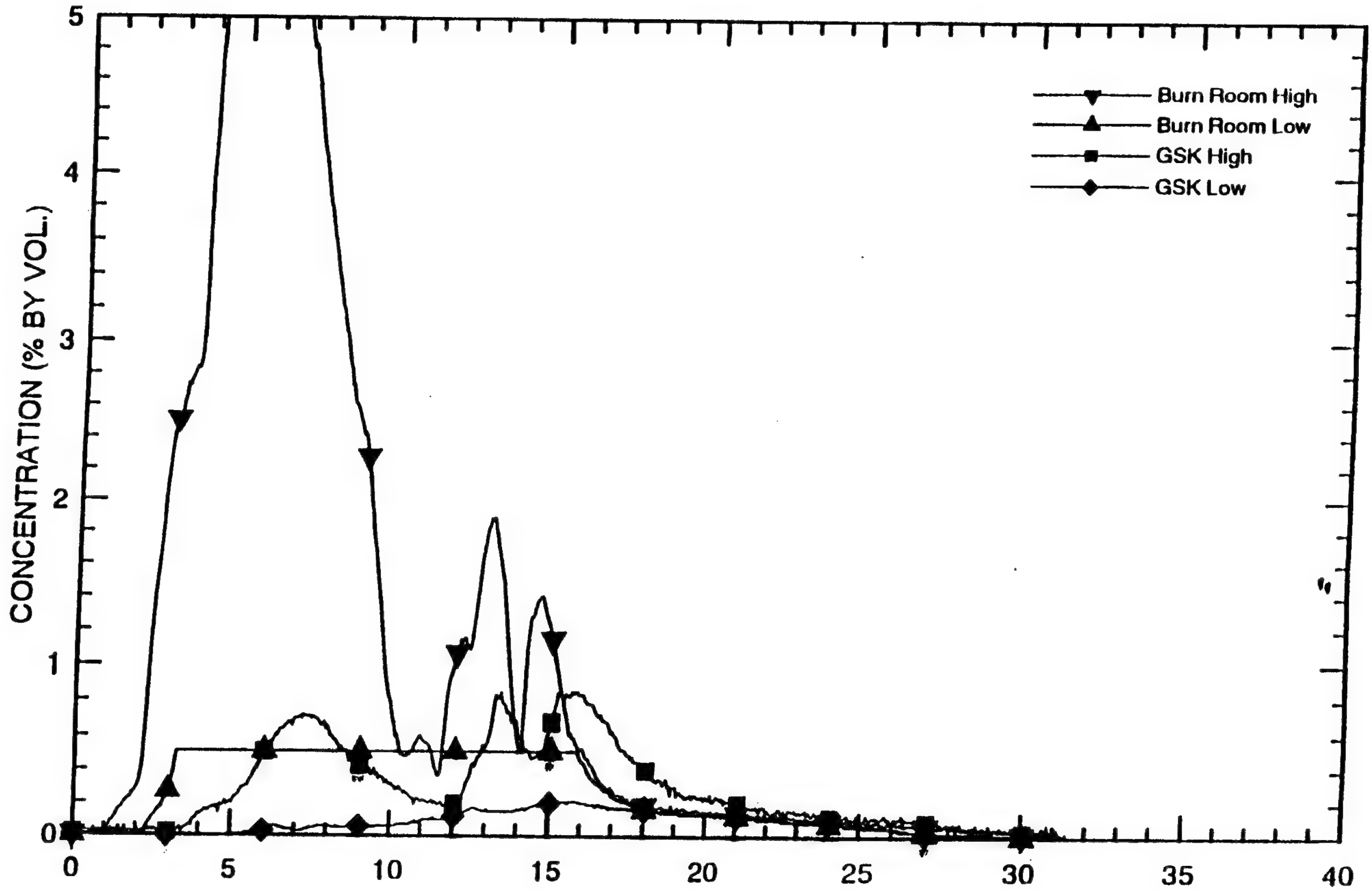


Fig. B175 - Carbon monoxide (CO) concentrations for FOG_19

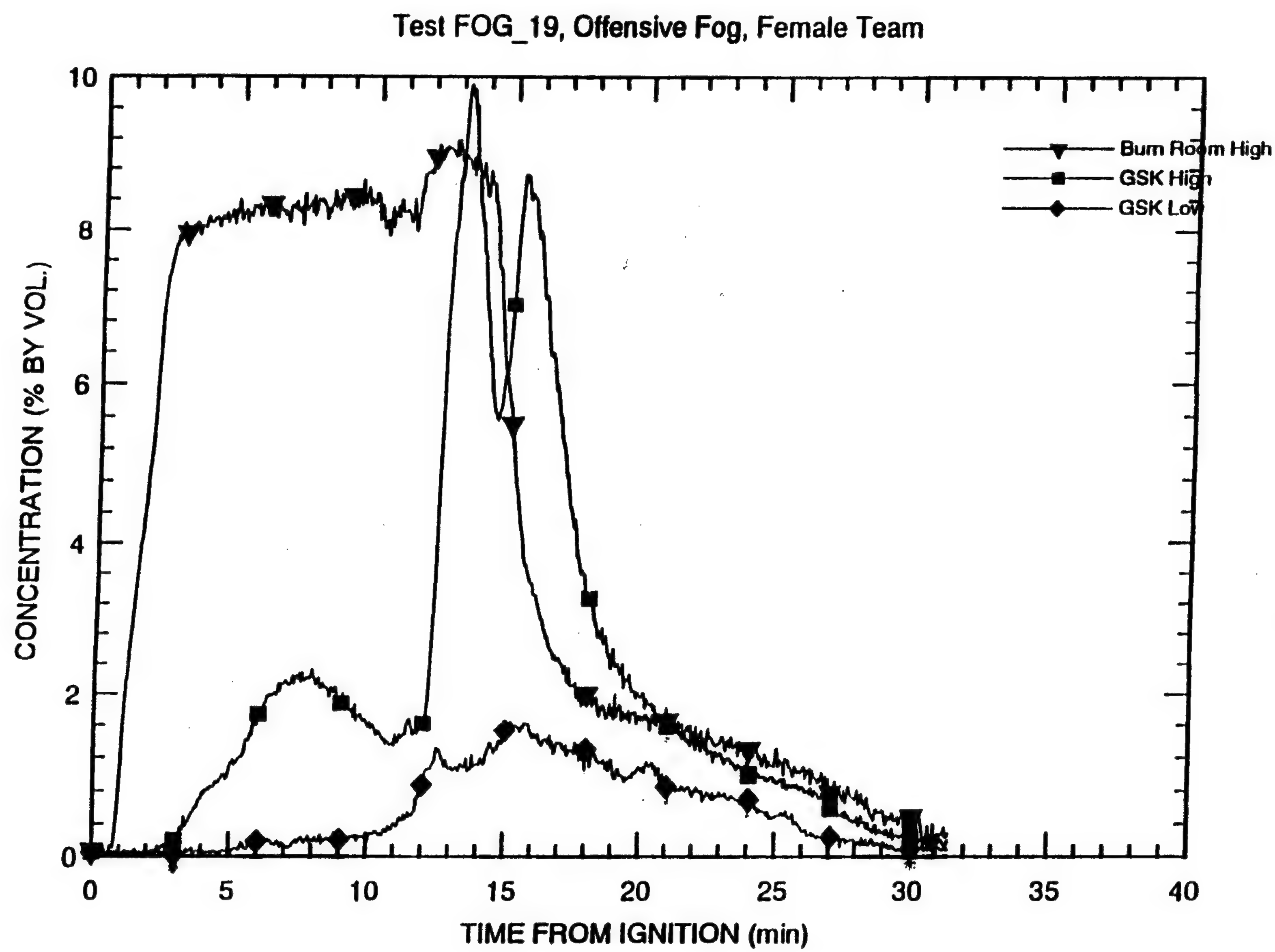


Fig. B176 - Carbon dioxide (CO_2) concentrations for FOG_19

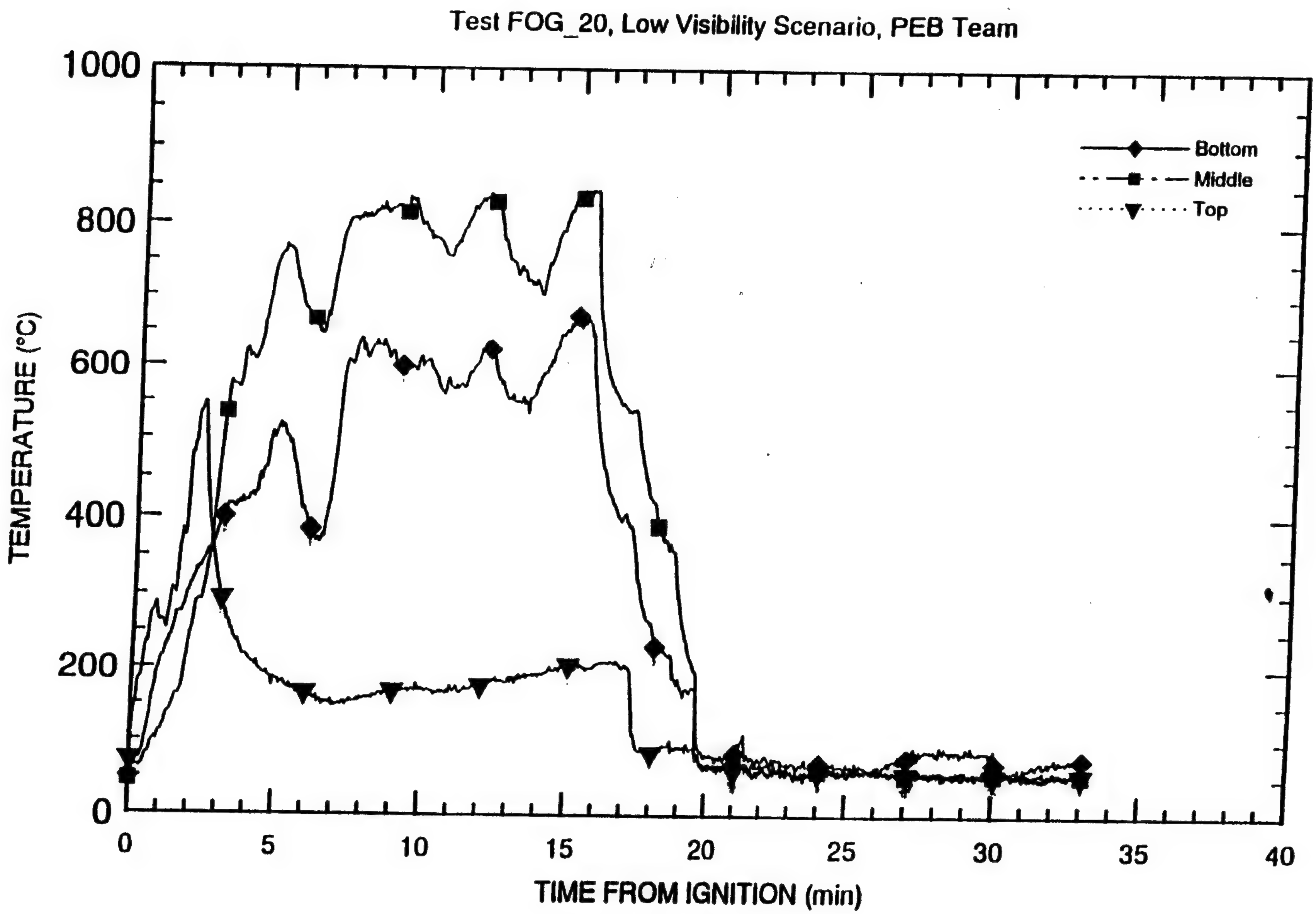


Fig. B177 - Wood crib #1 thermocouples for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

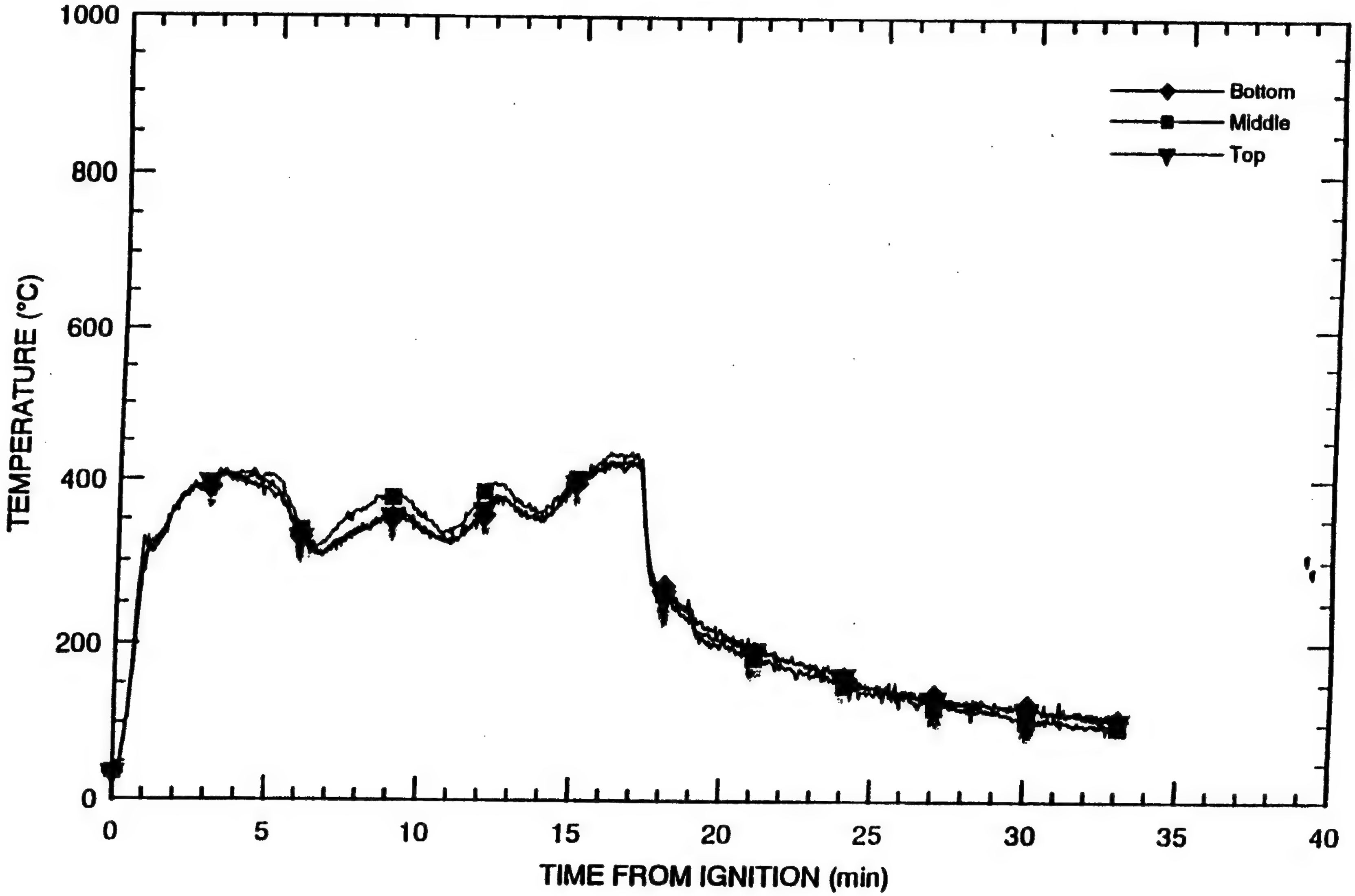


Fig. B178 - Wood crib #2 thermocouples for FOG_20

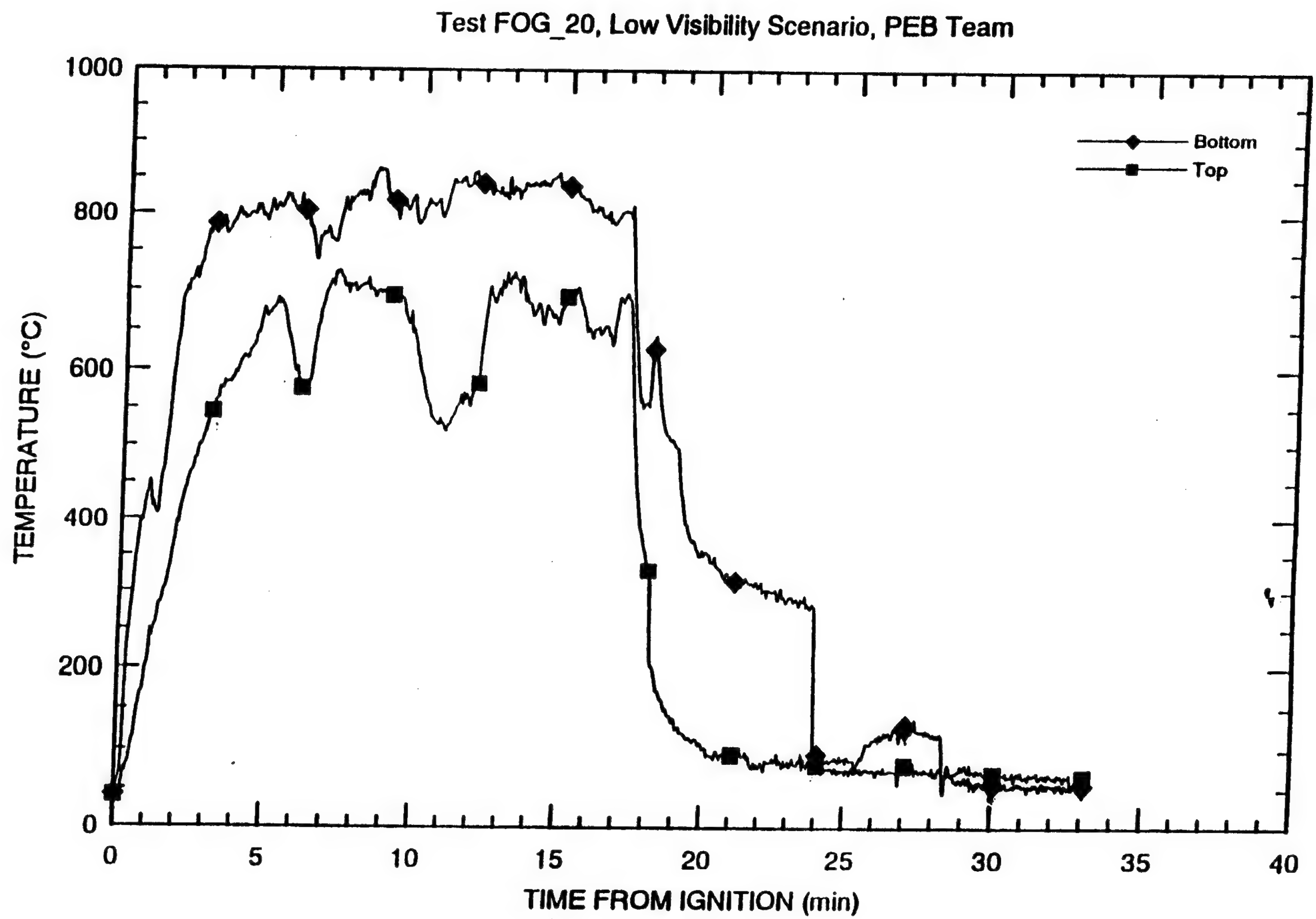


Fig. B179 - Wood crib #3 thermocouples for FOG_20

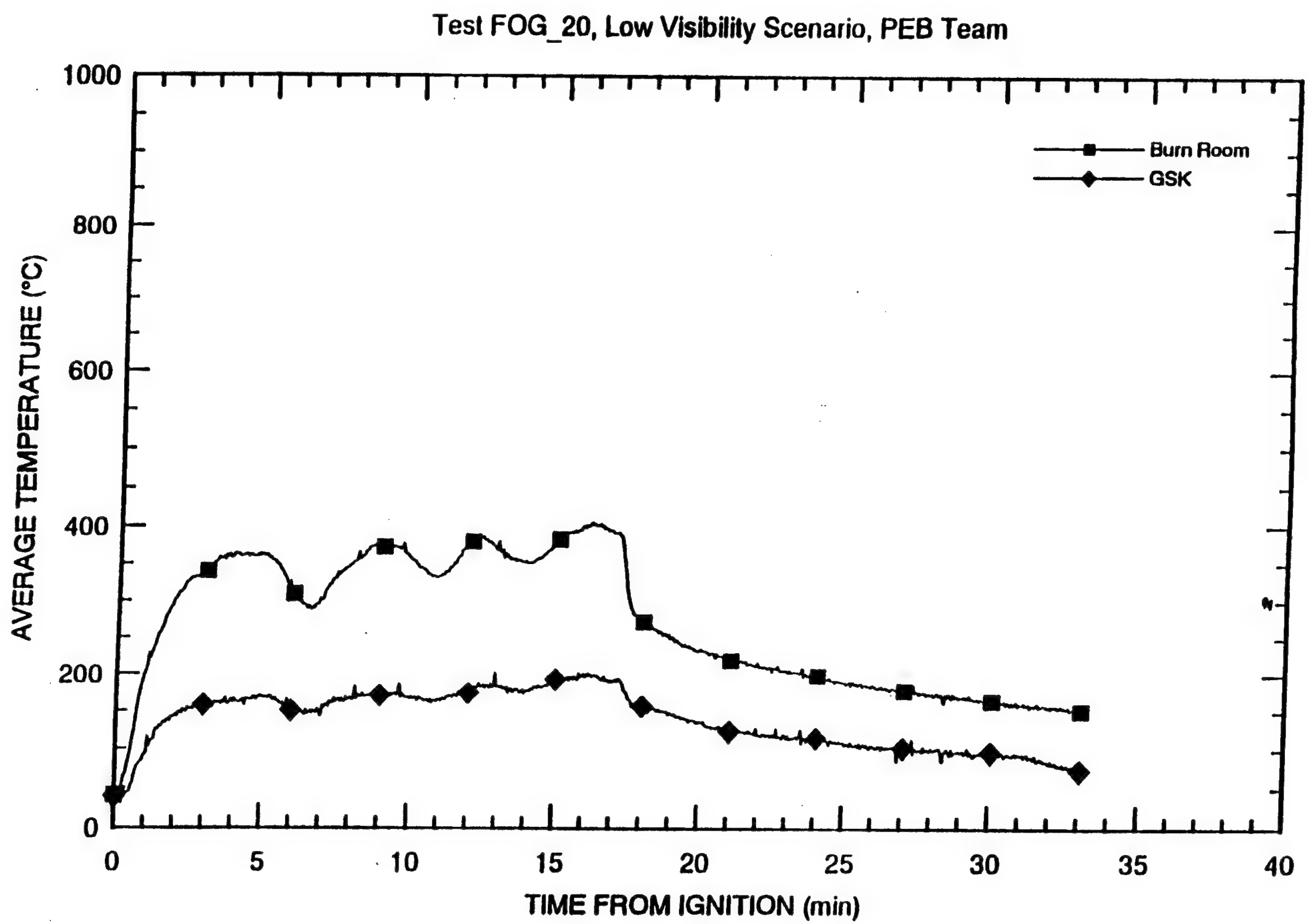


Fig. B180 - Average of overhead thermocouples for FOG_20

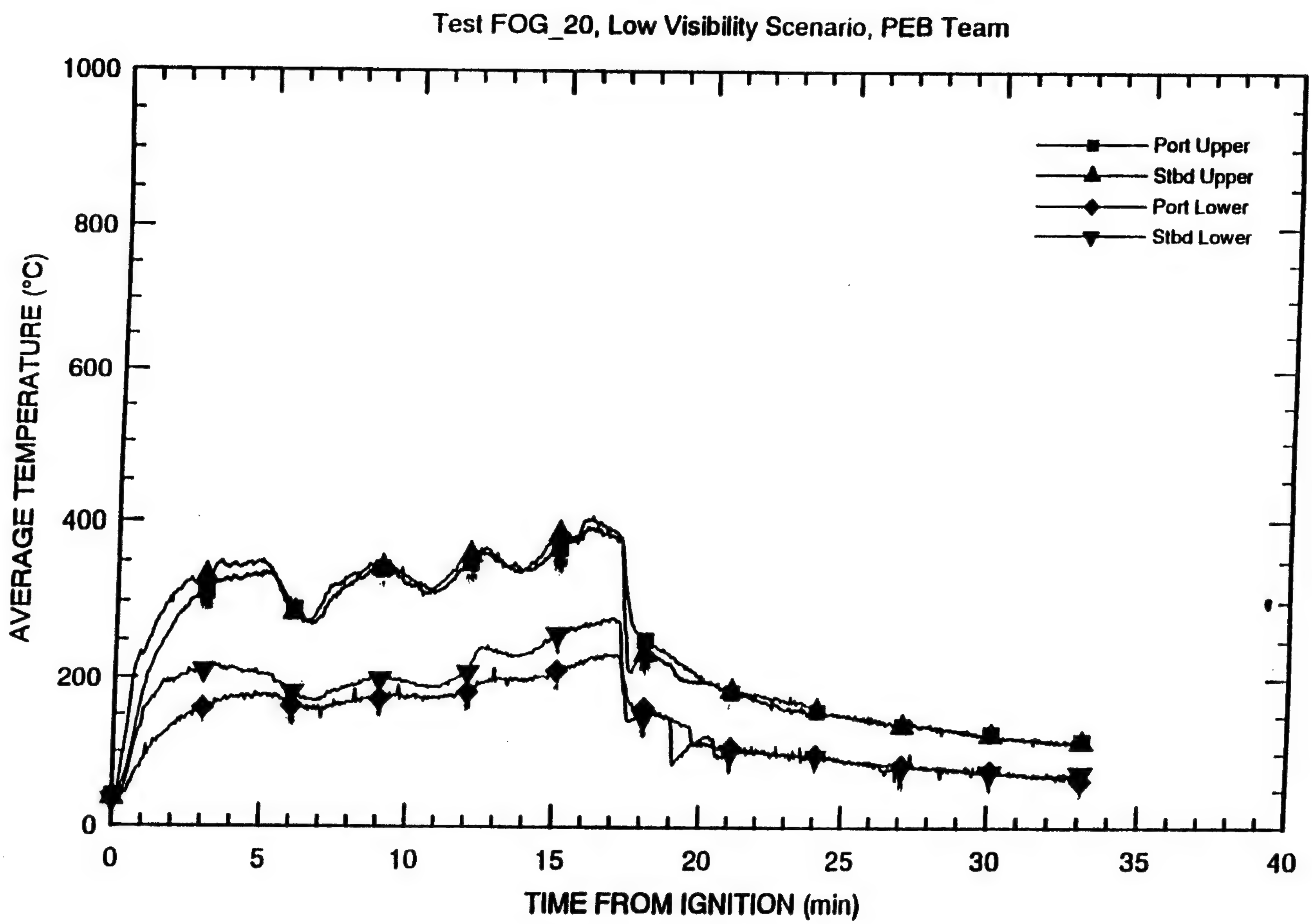


Fig. B181 - Burn room thermocouple string averages (upper vs. lower) for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

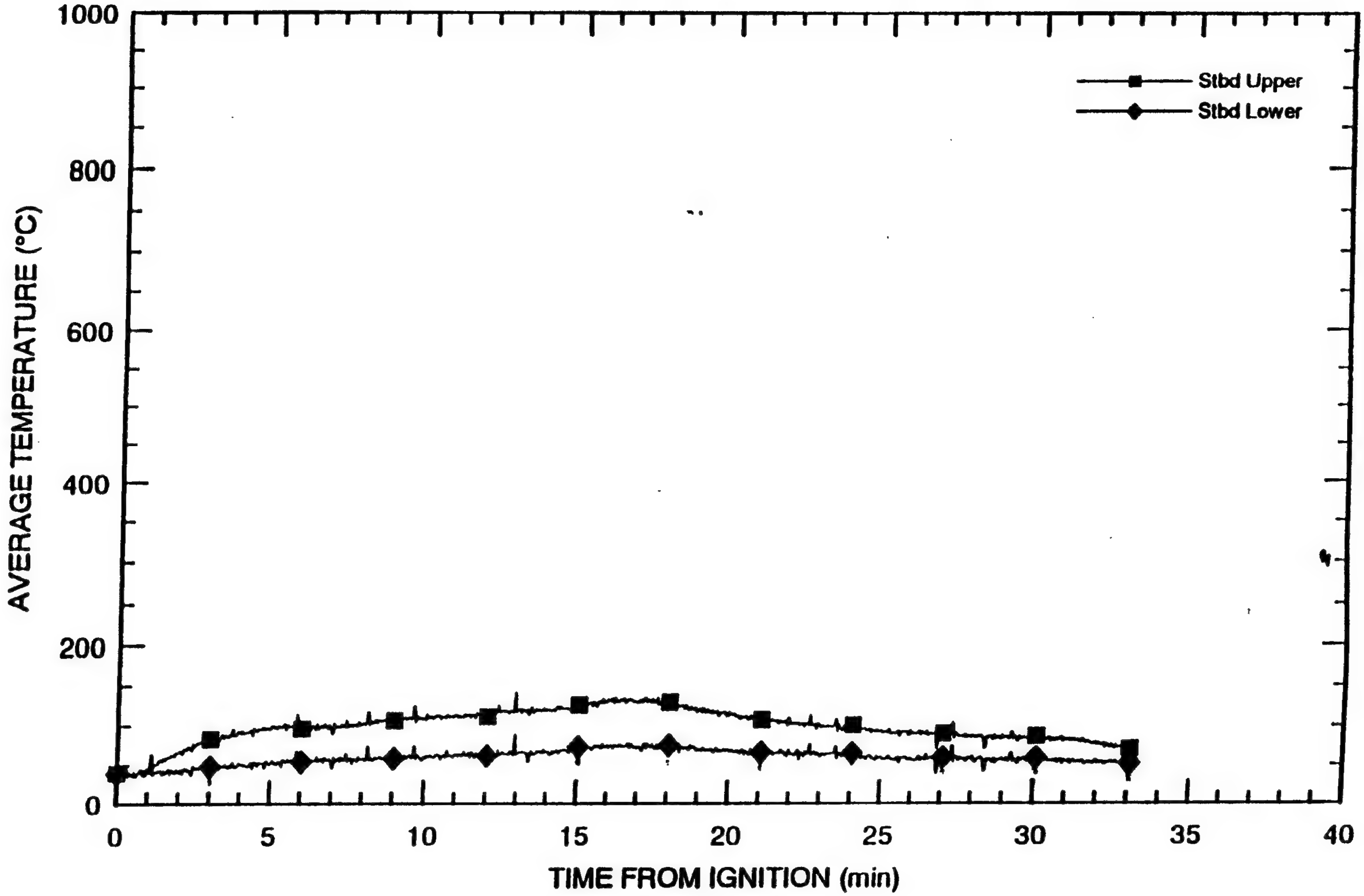


Fig. B182 - GSK thermocouple string averages (upper vs. lower) for FOG_20

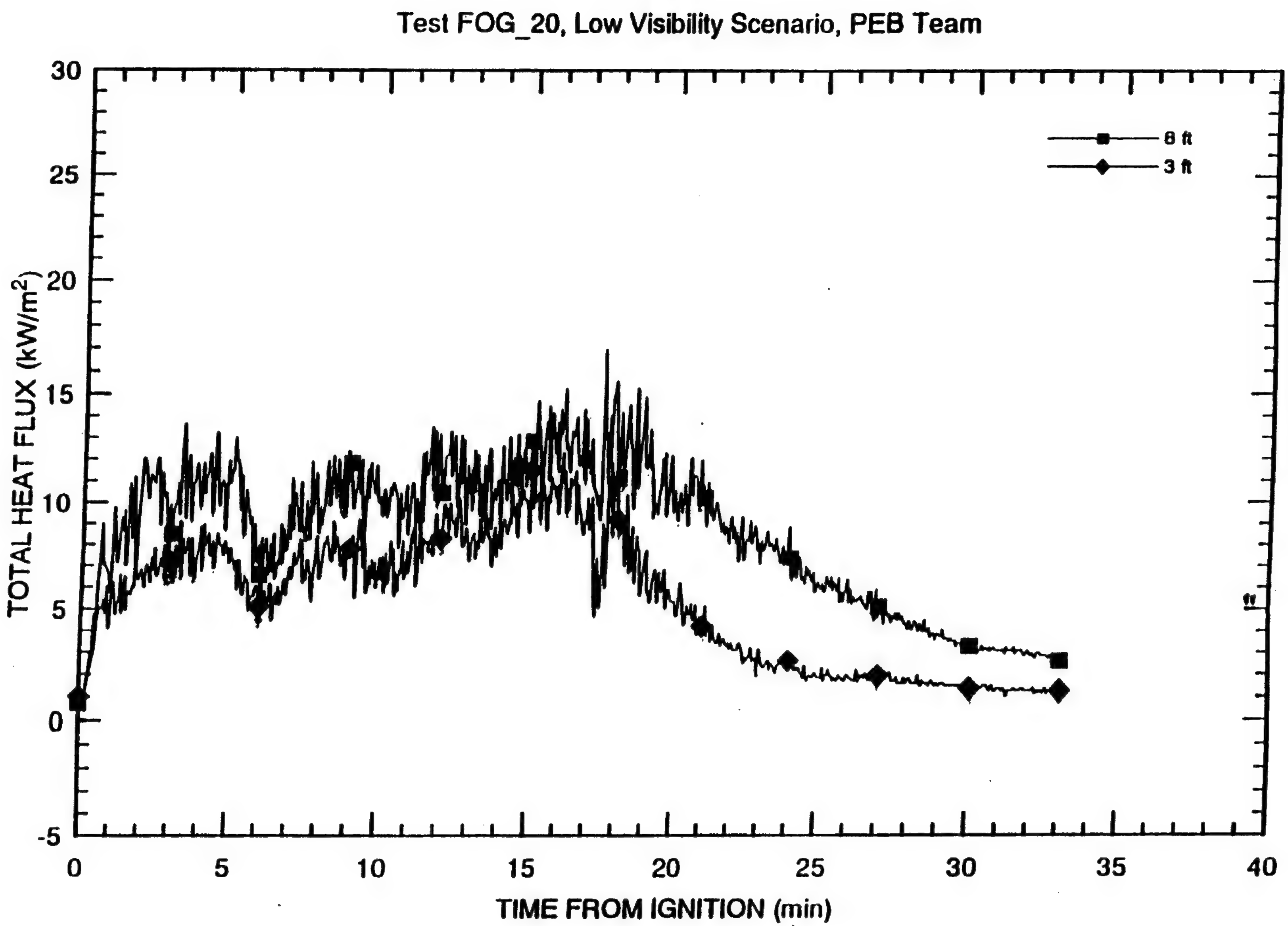


Fig. B183 - Burn room calorimeters for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

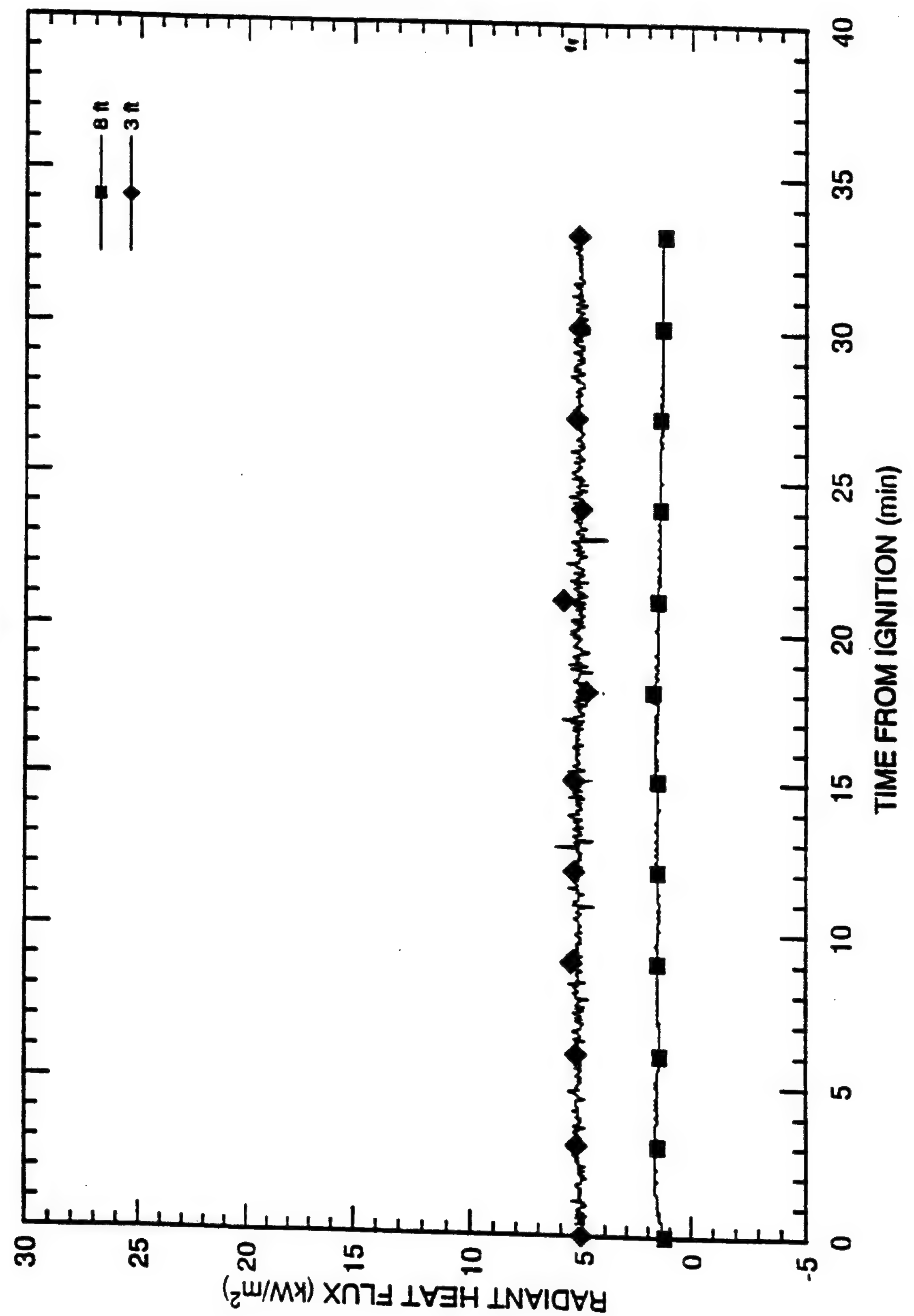


Fig. B184 - Burn room radiometers for FOG_20

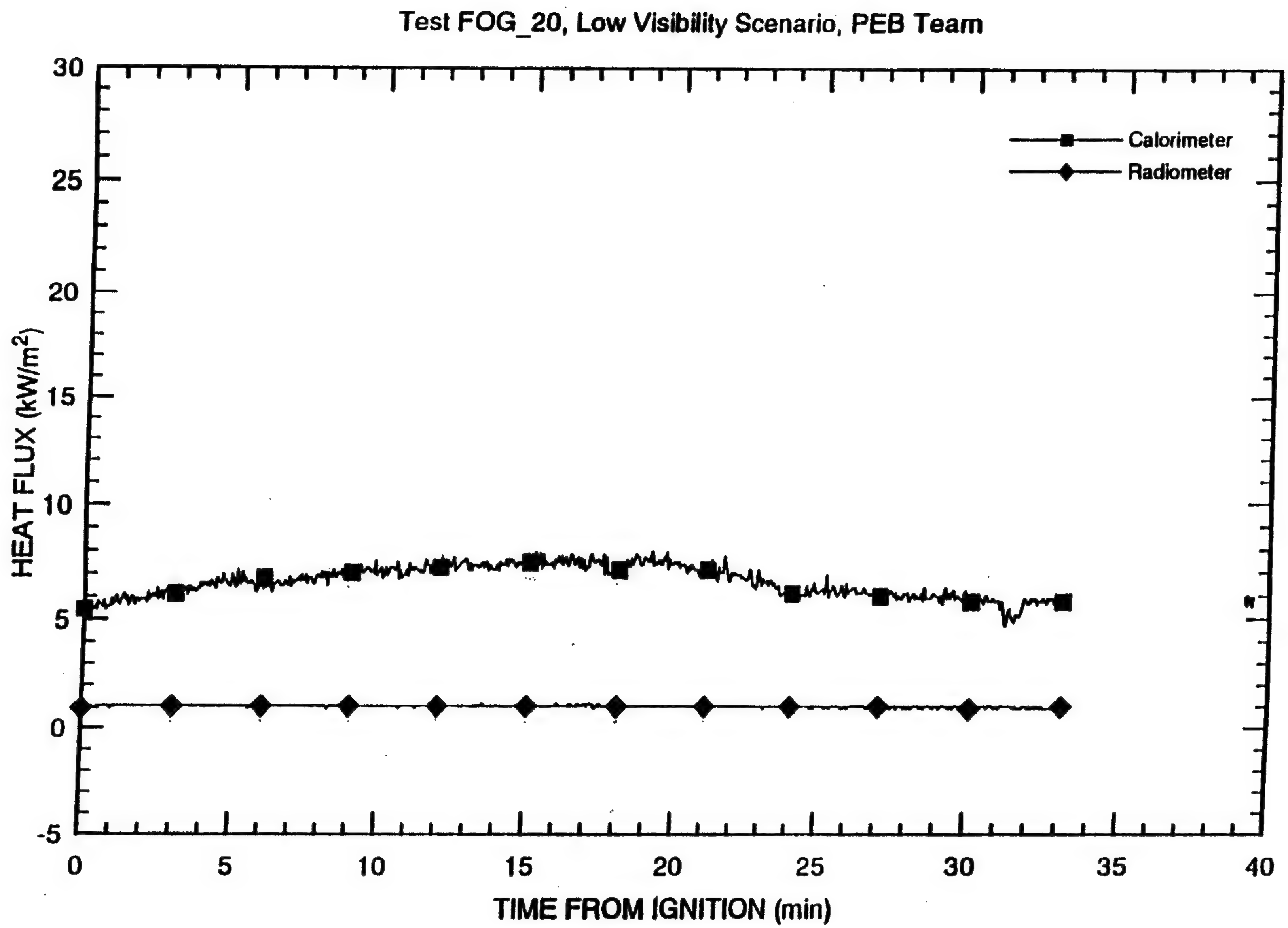


Fig. B185 - GSK radiometer and calorimeter for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

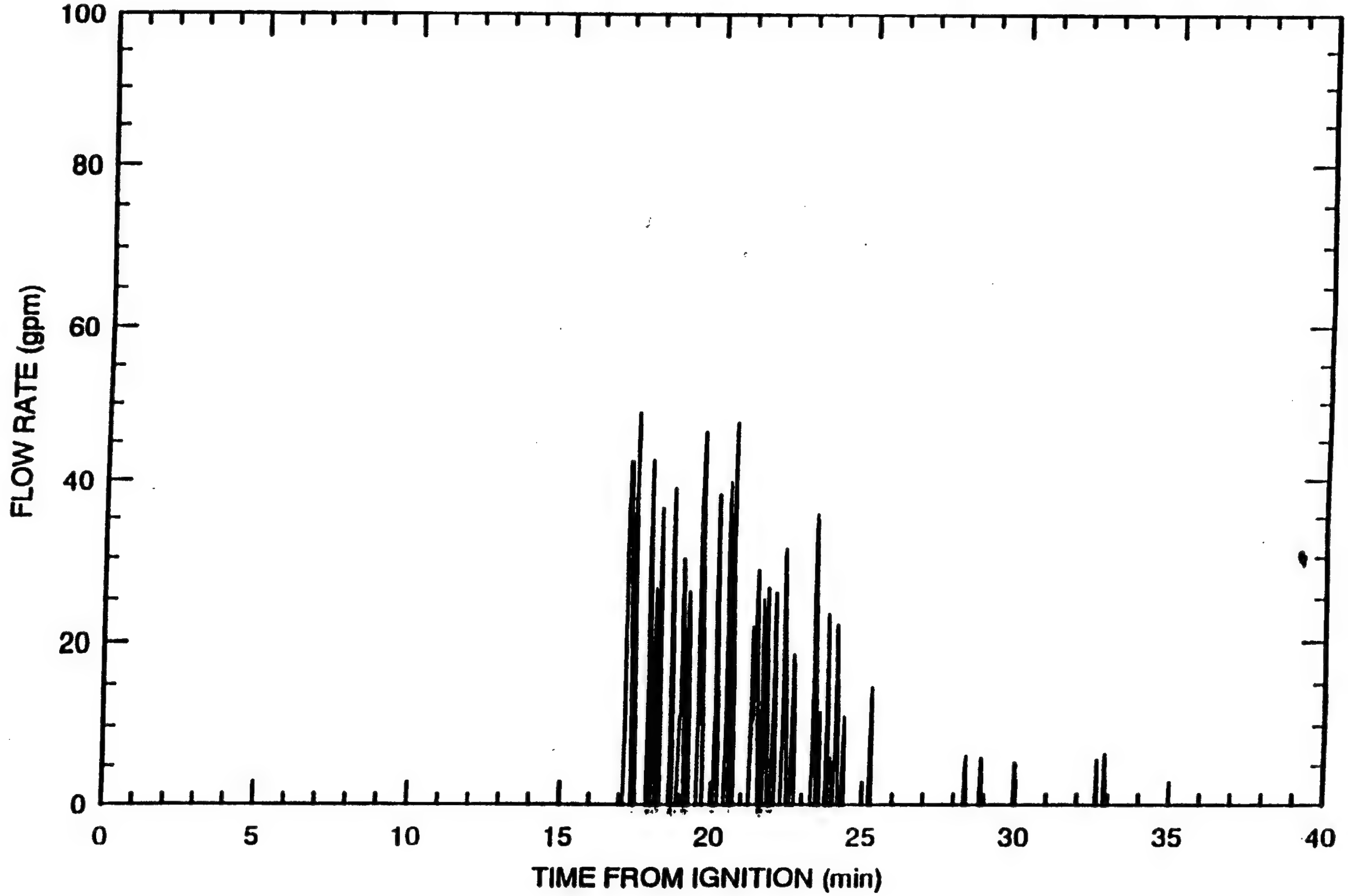


Fig. B186 - Water flow rate for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

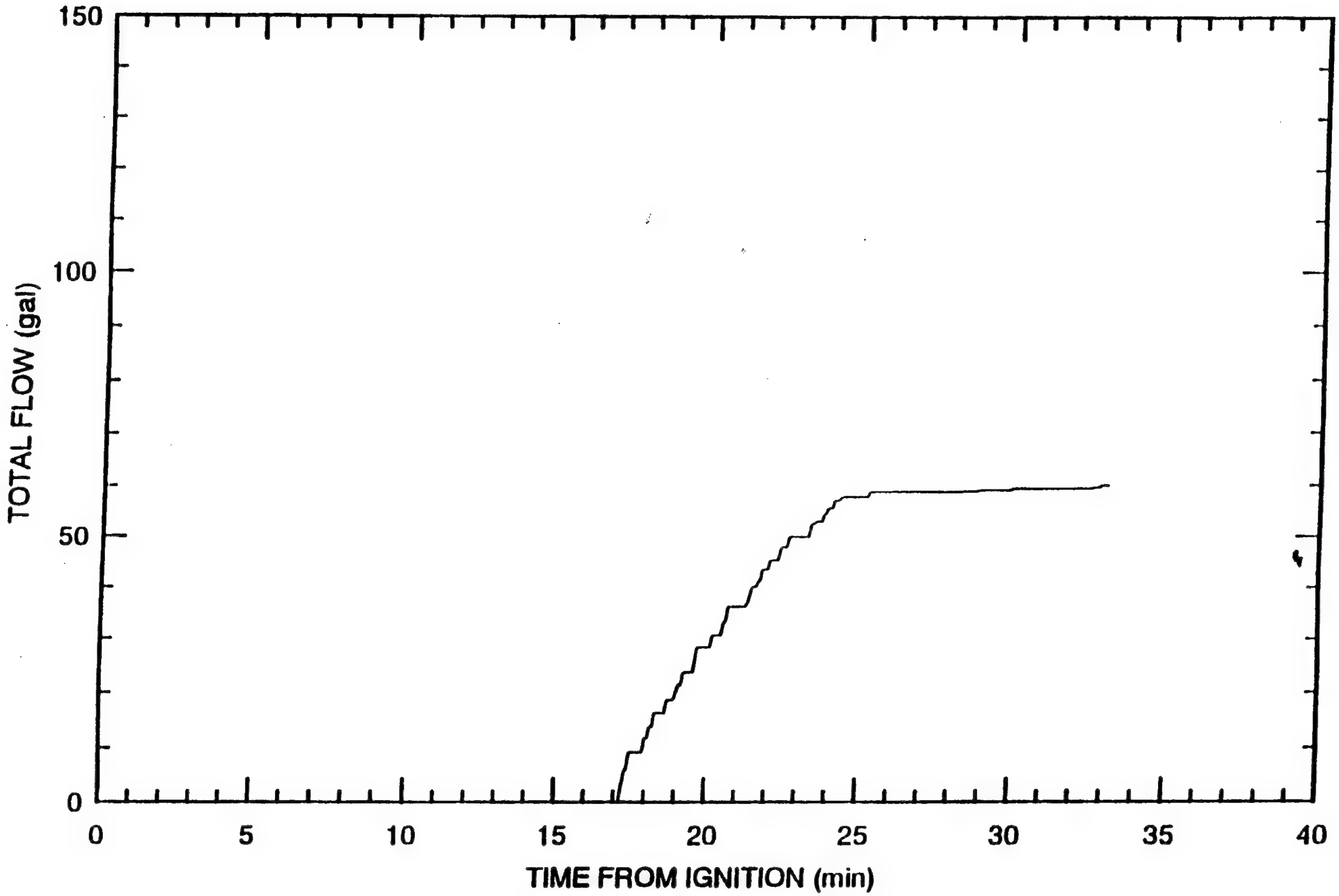


Fig. B187 - Cumulative water flow for FOG_20

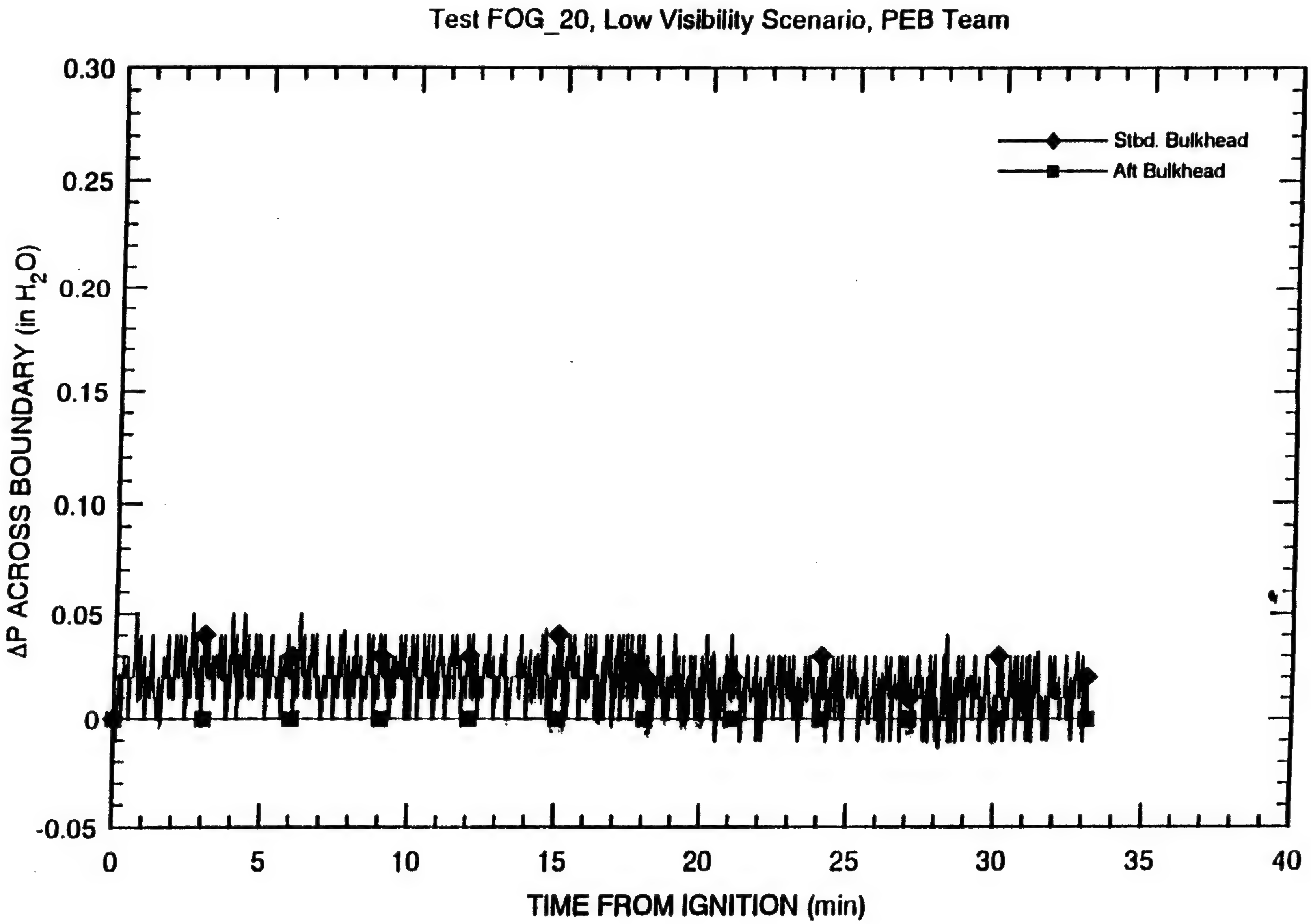


Fig. B188 - Pressure differential across burn room boundaries for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

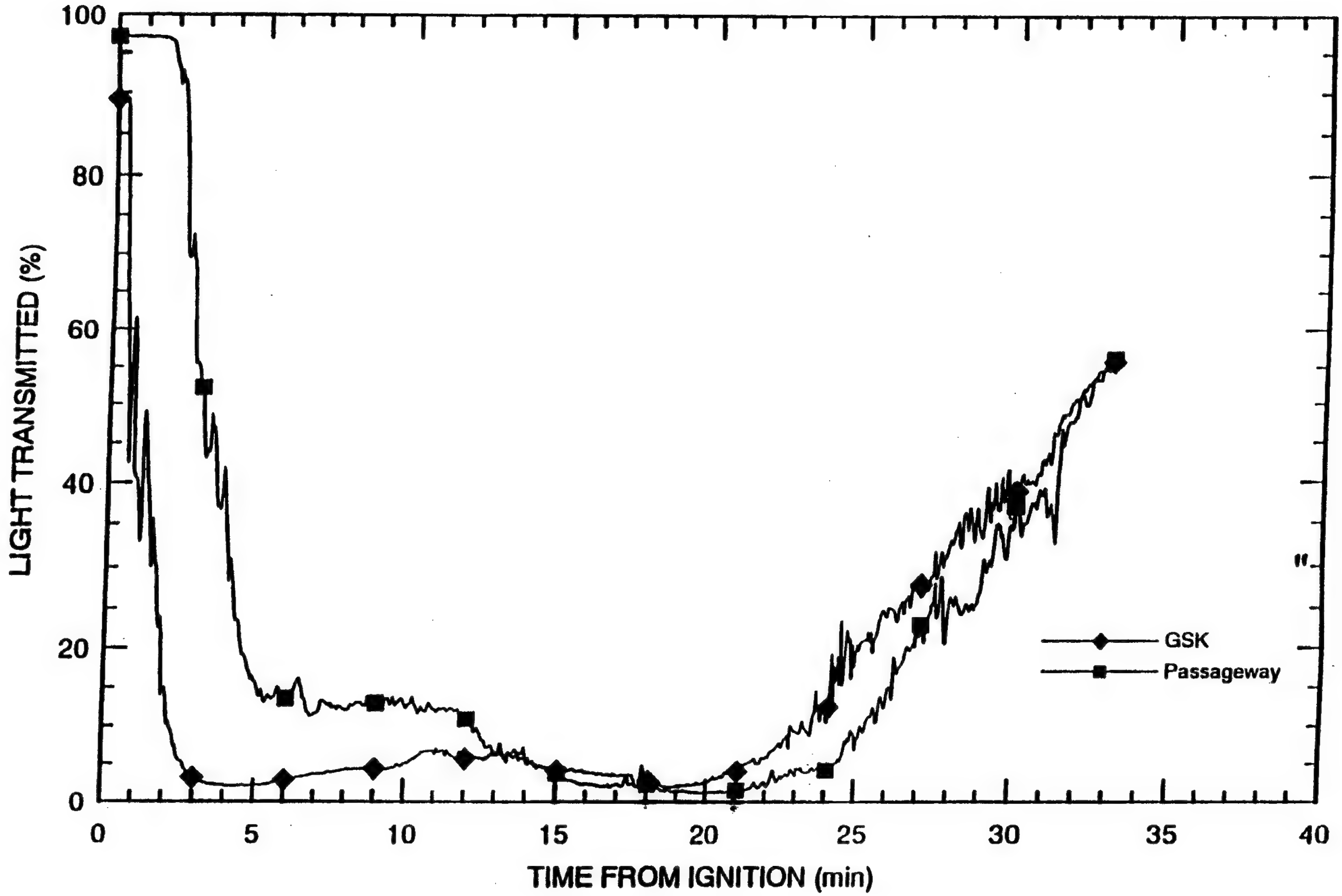


Fig. B189 - Smoke Obscuration for FOG_20

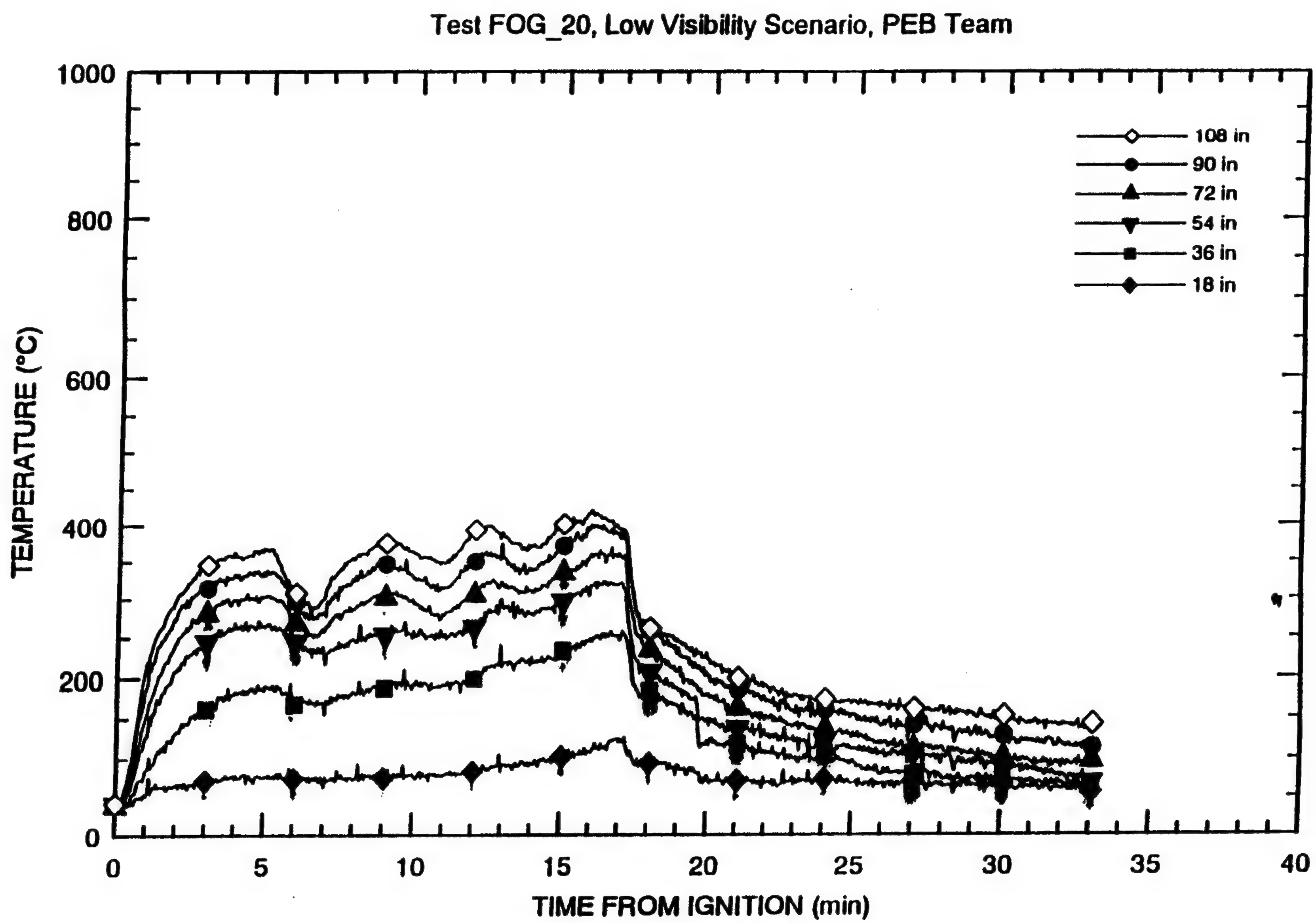


Fig. B190 - Port outer (2-18-2) thermocouple tree for FOG_20

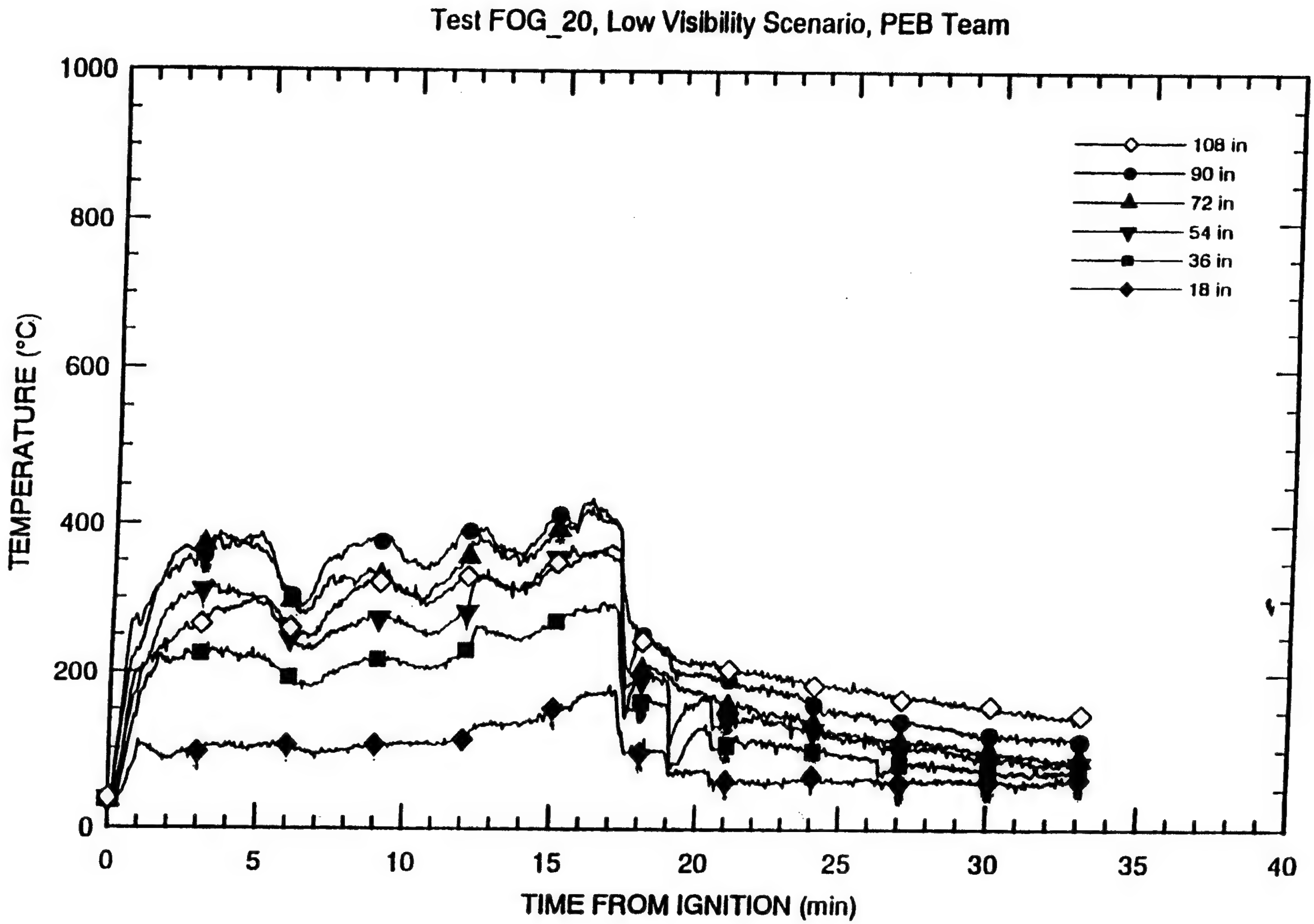


Fig. B191 - Port inner (2-19-0) thermocouple tree for FOG_20

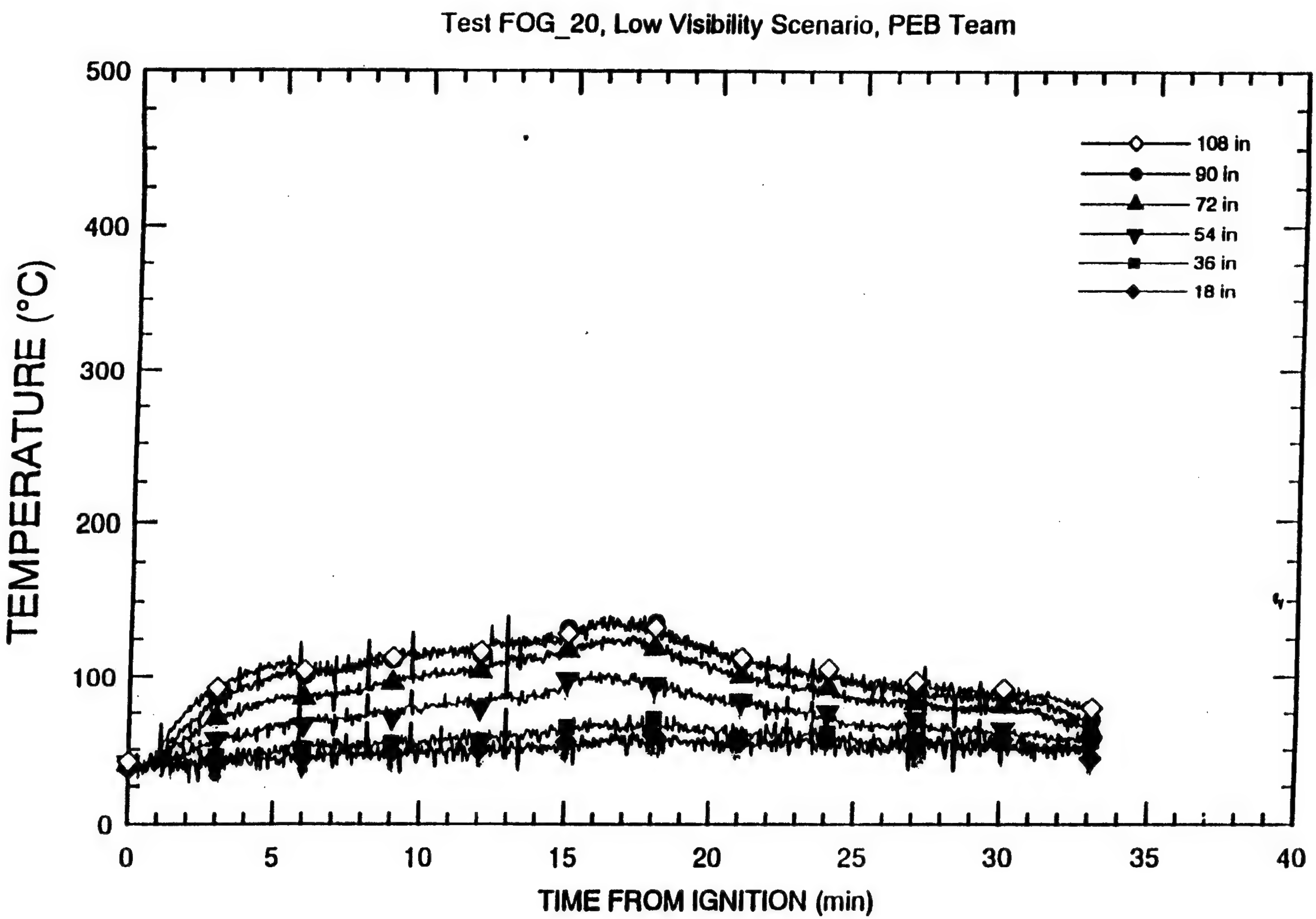


Fig. B192 - Starboard outer (2-21-3) thermocouple tree for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

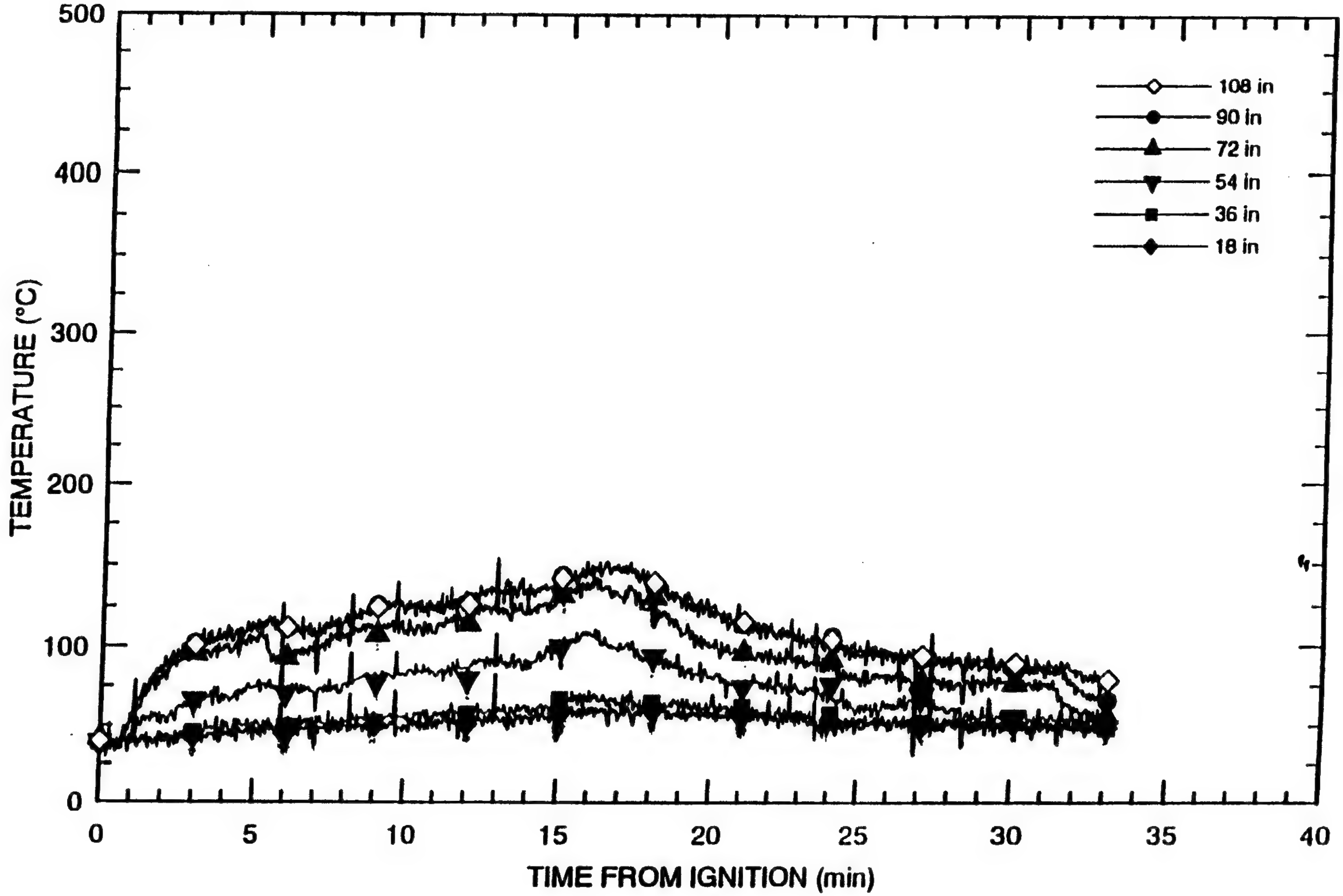


Fig. B193 - Starboard inner (2-21-1) thermocouple tree for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

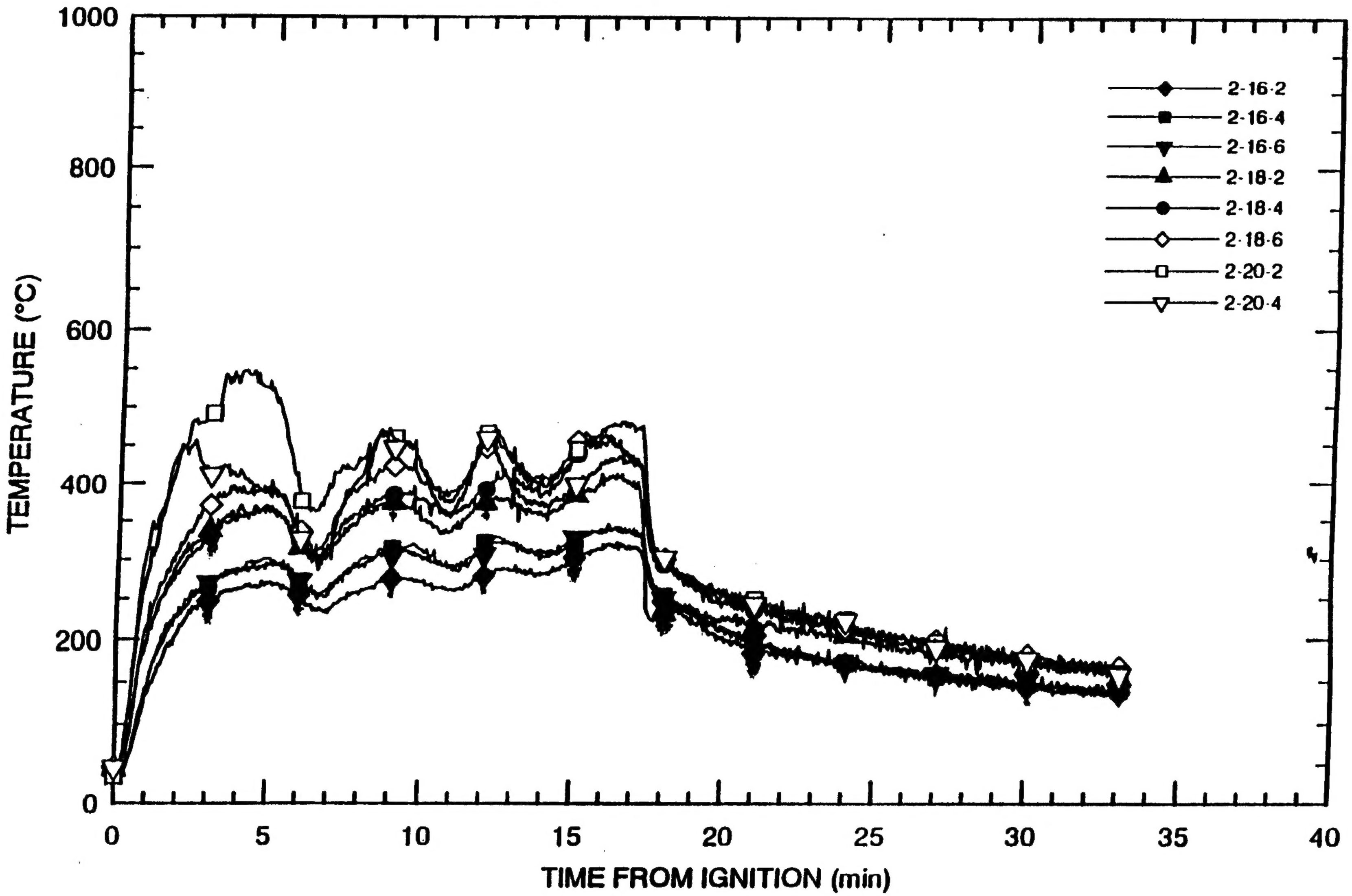


Fig. B194 - Burn room overhead temperatures for FOG_20

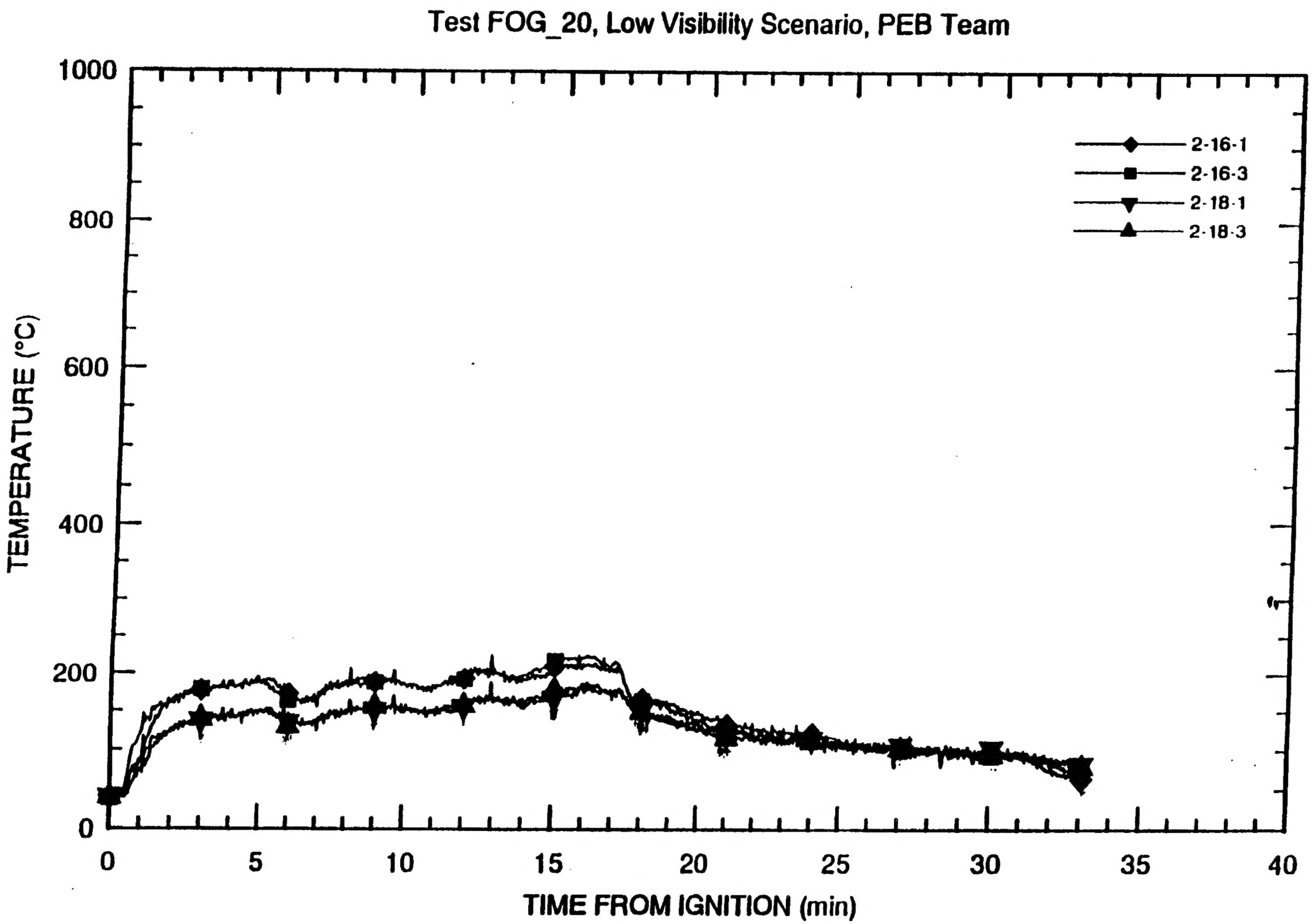


Fig. B195 - GSK overhead temperatures for FOG_20

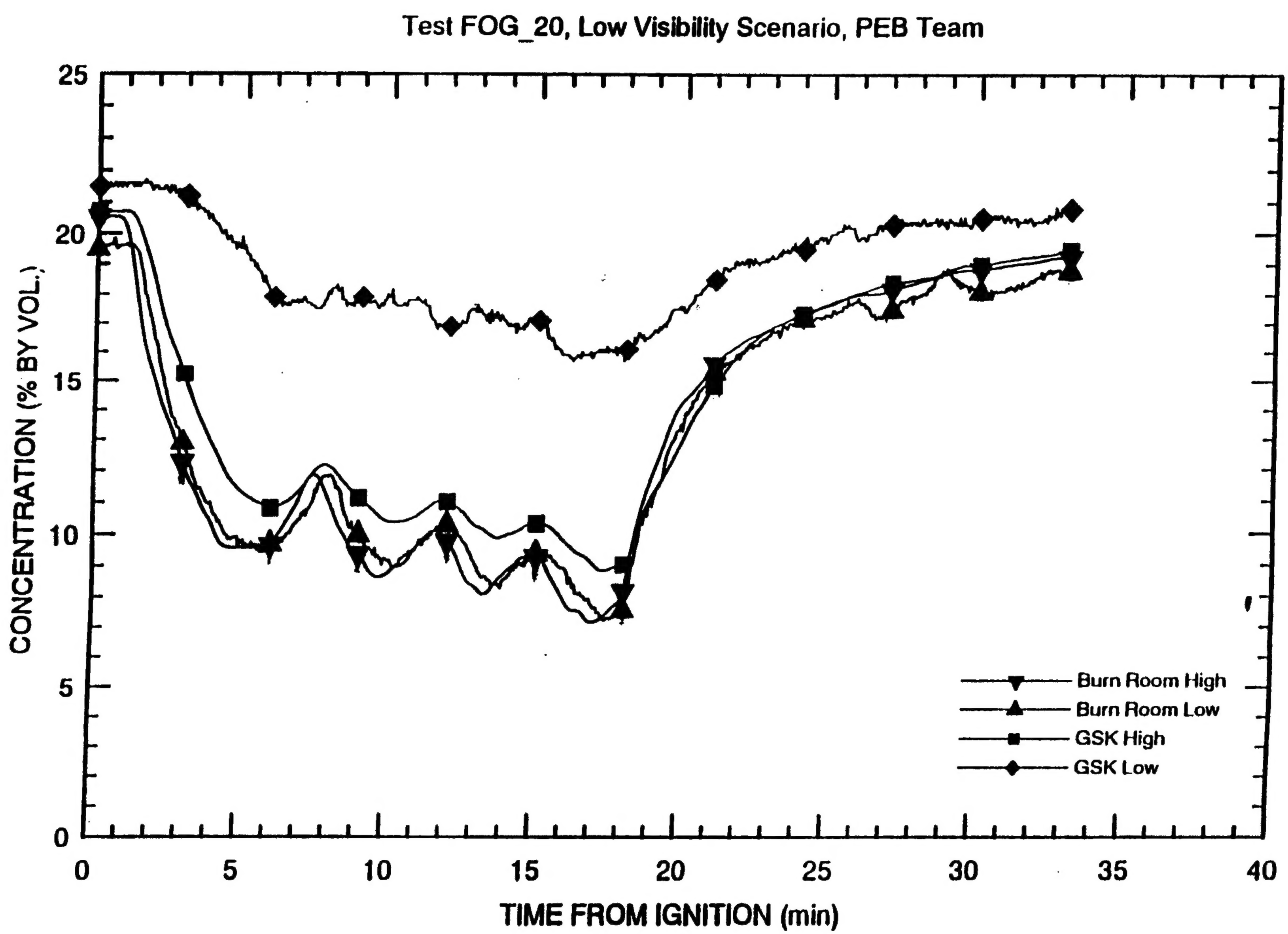


Fig. B196 - Oxygen (O_2) concentrations for FOG_20

Test FOG_20, Low Visibility Scenario, PEB Team

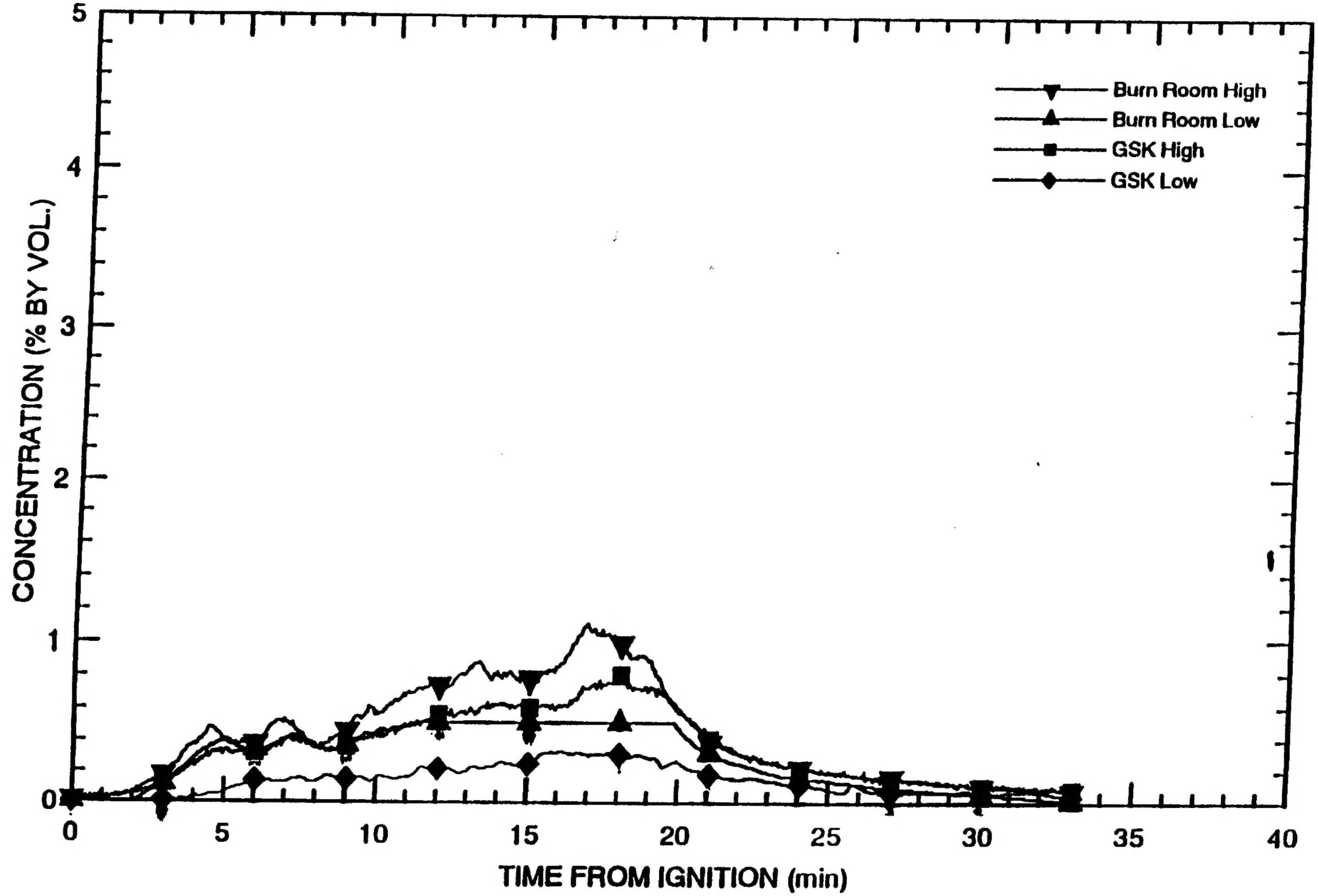


Fig. B197 - Carbon monoxide (CO) concentrations for FOG_20